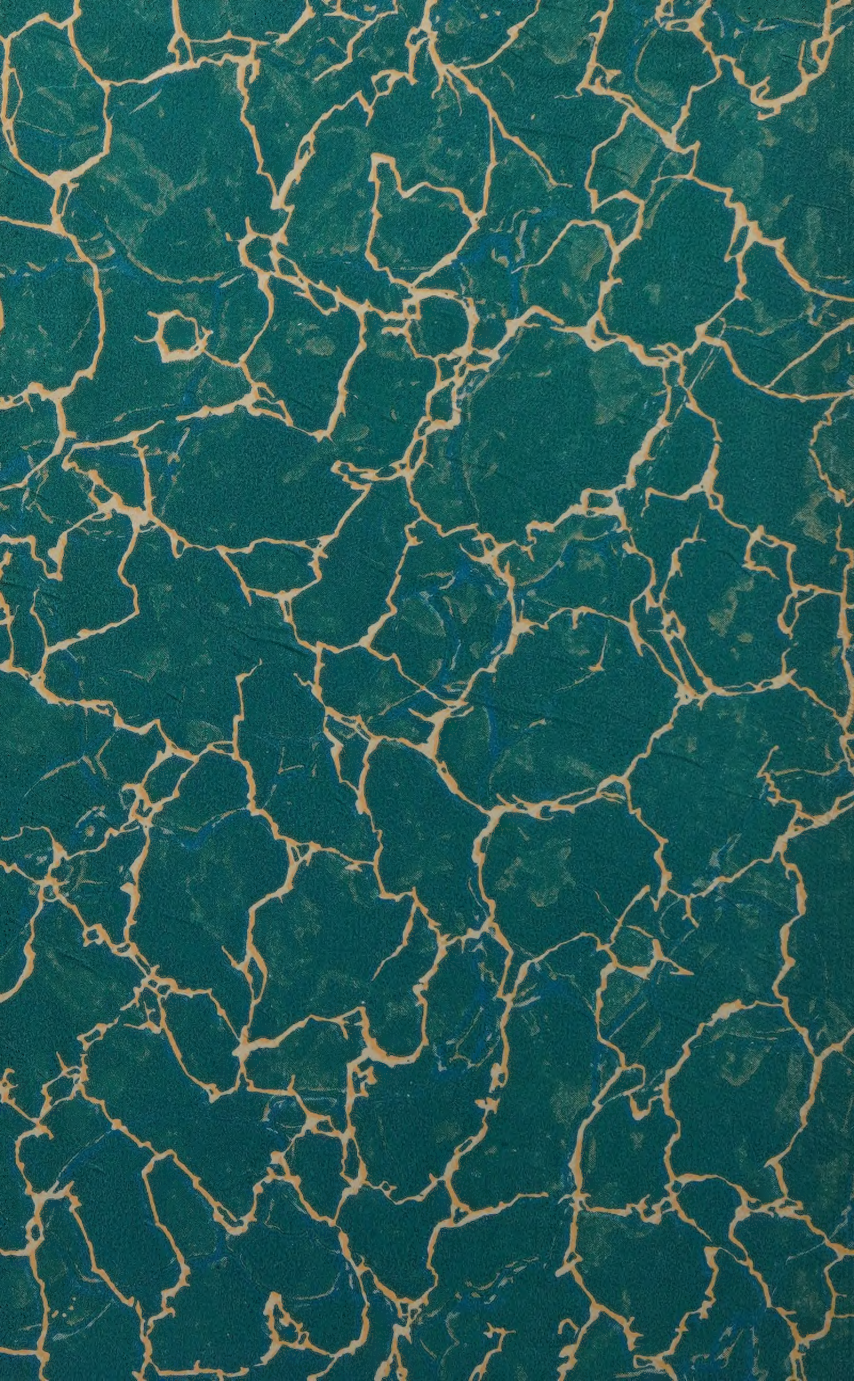
MACHINE SKETCHING

INTERNATIONAL
TEXTBOOK COMPANY
SCRANTON, PA.



Machine Sketching

By
I.C.S. STAFF

MACHINE SKETCHING

N
208

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Machine Sketching: Copyright, 1929, by International Textbook Company.

Copyright in Great Britain

All rights reserved

Printed in U. S. A.

Press of
International Textbook Company
Scranton, Pa.

83473

CONTENTS

NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

MACHINE SKETCHING

Pages

Sketches of Machine Details 1–81

Materials and Methods Used 1–13

Value of sketches; General requirements of sketches; Practice exercises for sketching; Drawing curved lines.

Examples of Sketching 14–48

Pieces Shown by Single Views 14–20

Square washer; Stop-pin; Bolt; Size of sketch; Piston rod.

Pieces Shown by Two Views 21–44

Stuffingbox gland; Finish marks; Practical suggestions; Crank; Arrangement of dimensions; Partial section; Conventional sections; Shaft coupling; Spur gear; Bevel gear.

Pieces Requiring More Than Two Views 45–48

Measurements 49–64

Measuring Instruments 50–54

Two-foot rule; Steel rules and tapes; Adjustable square; Calipers; Plumb-bob; Surface gauge.

Taking Measurements 54–64

Straight linear measurements; Distance between parallel faces; Outside diameters; Inside dimensions; Distance between centers; Distance between centers of gear-wheels; Curved outlines and fillets.

Pictorial Sketching 65–81

Isometric Drawing 65–71

Use of pictorial sketches; Isometric axes; Angle plate; Stop pin; Isometric drawing of circles.

Oblique Drawing 72–76

Advantages of oblique drawings; Washer; Wall bracket; Oblique drawing of circles.

Pictorial Sketches of Piping 77–81

Advantages; Conventional symbols; Piping diagrams; Developed piping diagram.

MACHINE SKETCHING

Serial 2249-2 Edition 1

SKETCHES OF MACHINE DETAILS

MATERIALS AND METHODS USED

INTRODUCTION

1. Value of Sketches.—Ordinarily, the parts that form a machine are constructed from the information given on drawings that show the shape and dimensions of each piece. Such drawings, known as working drawings, are usually made accurately by the aid of drawing instruments. But there are circumstances under which drawings must be made without the use of instruments, and such drawings are called sketches. They are made freehand and are more or less rough and crude, depending on the care and ability of the sketcher; but even if they are somewhat rough, they serve their purpose if they show the shape and necessary dimensions of the piece. As an example of the value of sketching, suppose that a machine in some locality far from a repair shop is damaged by the breaking of a part, and that no spare parts are available. It then becomes necessary to make a sketch of the broken piece, showing its general form and giving all its dimensions, so that the mechanic to whom the sketch is sent can make an exact duplicate of the piece.

2. A sketch must contain all the essential information that is given by a working drawing; but as it is made freehand, it is not drawn accurately to scale. In other words, the actual dimensions of the piece in the sketch are quite likely to be out of pro-

COPYRIGHTED BY INTERNATIONAL TEXTBOOK COMPANY. ALL RIGHTS RESERVED

portion more or less; but if the correct dimensions are placed on the sketch and the lines of the sketch give a clear idea of the shape of the piece, the sketch will fulfil its purpose. A sketch containing the necessary dimensions and explanatory notes as to the materials may be used directly as a working drawing from which to construct the part; or, if desired, it may be used as the basis from which a draftsman can prepare an accurate working drawing of the piece, to scale. The real difference between a sketch and a mechanical drawing, therefore, is that one is a rough representation of an object and the other is a finished drawing showing all parts in their true proportions.

3. General Requirements of Sketches.—As sketches are made freehand, and often under such conditions as to make drawing difficult, it is necessary that the sketcher acquire facility in making lines. The lines that make up a sketch may be horizontal, vertical, or inclined, and they may be straight or curved. Usually a sketch comprises a combination of straight and curved lines, and the only way to acquire ease and rapidity in drawing sketches is by continued practice. Such practice naturally begins with the drawing of straight lines of different lengths and of varying degrees of inclination; then follows the drawing of curved lines; and finally, lines made up of straight and curved parts are practiced. Curved lines may have uniform curvature, as in the case of circles and arcs of circles; or they may be of varying curvature, as in the case of ellipses and other lines in which the change of curvature varies. The ability to make a neat sketch is desirable, but not necessary, because the main purpose of a sketch is to illustrate clearly the form and size of a piece.

SKETCHING MATERIALS

4. Paper and Pencils.—The only materials needed for making a sketch are a pencil, a sheet of paper, and an eraser. The eraser is of value in rubbing out lines that have been incorrectly drawn. It may be a piece of art gum or of soft rubber; but a more convenient form is a rubber attached to the end of the pencil used for sketching. The paper may be of any convenient size, but it should preferably be plain and of letter-

sheet size, $8\frac{1}{2}$ by 11 inches, put up in pad form with a stiff cardboard backing. As the sketches are made, the sheets may be torn off, one by one. The paper should be tough and fairly heavy, so as to withstand erasures and rough handling. Manila paper is very satisfactory. The lead pencil used should be of medium hardness, so that lines drawn by it will not smudge, and yet may be rubbed out without too much trouble, when that becomes necessary.

5. Cross-Section Paper.—The use of cross-section paper, or squared paper, will aid considerably in making sketches, because such paper is ruled with a series of light lines at right angles to one another, as shown in Fig. 1. For the sketching of machine details, the ruled lines should be $\frac{1}{8}$ inch apart, or 8 to the inch. With squared paper, the sketcher will find it a simple matter to draw horizontal and vertical lines; also, the regular spacing of the lines on such paper will enable him to draw his sketch more nearly to scale. However, it is well for the beginner to use plain, unruled paper, so as to train his hand to the drawing of lines and his eye to the proportioning of the parts of the sketches. If he relies too much on squared paper, he will find difficulty when he is forced to make sketches on plain paper. As most sketching is done on unruled paper, it is advisable for the beginner to do his work on sheets of that kind, and to be independent of the aid given by squared paper.

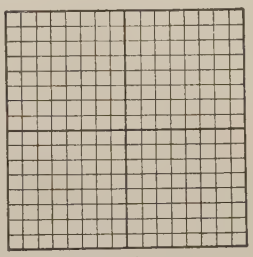


FIG. 1

PRACTICE EXERCISES FOR SKETCHING

6. Sharpening Lead Pencils.—The pencil used in drawing sketches should not have an extremely sharp point; rather, the point should be rounded and blunt, such as is found in the various makes of pencils in which the lead is contained in a hollow barrel and fed forwards as fast as it is worn away. A pencil of this type is self-sharpening. However, there are many people who still prefer the older form of pencil, shown in

Fig. 2 (*a*), which consists of a central lead fixed in a wooden holder. To sharpen such a pencil, the wood is cut away with a sharp knife so as to expose about $\frac{1}{4}$ inch of the lead, as in (*b*).

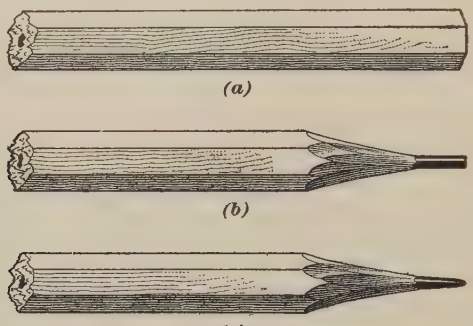


FIG. 2

Next, the projecting lead is brought to the shape shown in (*c*) by the use of the knife or by being rubbed on a strip of sandpaper.

7. Manner of Holding Pencil.—In all sketching of machine parts, the pencil should be held lightly between the thumb and the first and second fingers, as in Fig. 3 (*a*) and (*b*). This is

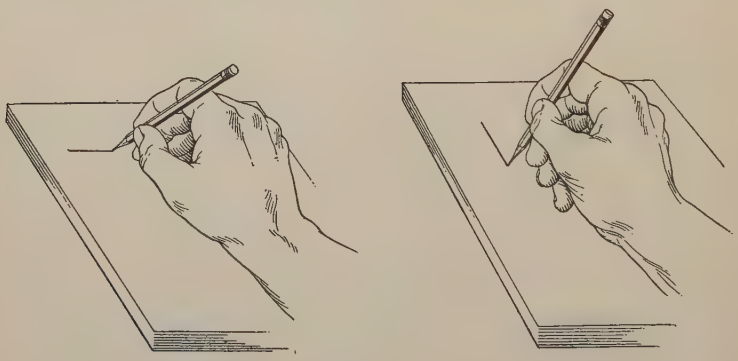


FIG. 3

simply the ordinary position in which a pencil is held for writing. Care should be taken not to grip it so tightly as to cramp the hand; in other words, there should be no strain on the

muscles of the hand and fingers, but instead a natural and easy hold on the pencil. Freedom of movement of the hand and forearm is necessary in sketching, and it cannot be obtained if the pencil is gripped tightly in the fingers. However, it is well to remember that the really important thing in sketching is to produce a satisfactory sketch, and so the manner of holding the pencil and of drawing the lines is of secondary importance. The foregoing position of the pencil is suggested because it is the one that would ordinarily be taken by the majority of persons.

8. Drawing Straight Lines.—The simplest exercise in learning to sketch is to draw straight horizontal lines, such as those shown in Fig. 4 (*a*). In drawing such straight lines, it being assumed that the person doing the work is right-handed, the pencil is moved from left to right. The ends of the third and fourth fingers rest on the surface of the paper and serve to support and guide the hand. The forearm, too, may rest partly on the sketch pad, and thus furnish an additional means of steadying the movement of the pencil.

Drawing short horizontal lines is easy. All that is required is to swing the hand at the wrist. But when long lines are to be drawn, the limit of the wrist swing is passed, and there is a tendency for the lines to curve upwards at the middle. The reason is that the forearm is pivoted at a point near the elbow, and the arm and hand, held rigid, are swung on this pivot, which makes the pencil travel in the arc of a circle and produce a curved line. To correct this tendency, the whole forearm must be slid along horizontally in the direction in which the line is being drawn. Practice should be continued until the hand is trained to draw straight horizontal lines of any required length.

9. The next step is to learn to draw vertical lines of different lengths, as shown in Fig. 4 (*b*). Such lines may be produced entirely by movement of the fingers, the forearm being held stationary. Longer vertical lines, however, necessitate moving the hand and the forearm as a single rigid unit, the third and fourth fingers acting as guides. It is not absolutely necessary that vertical lines be drawn as just described. The sketching pad is of such size that it can be readily turned to any posi-

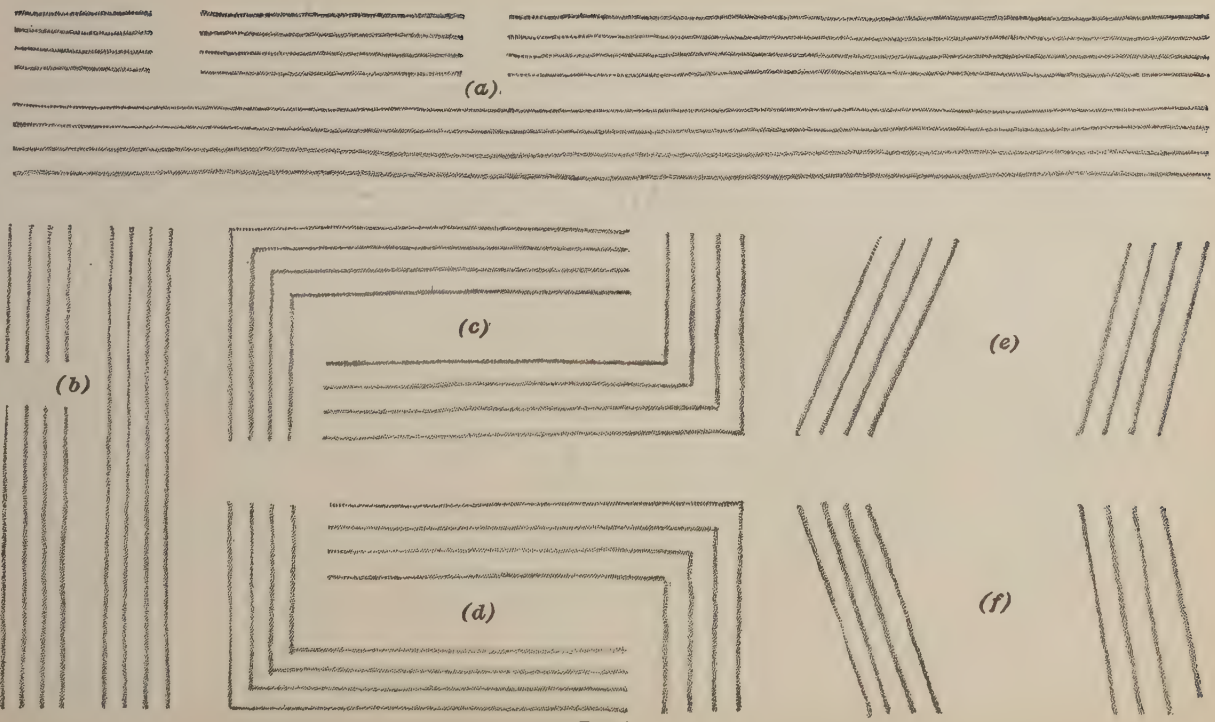


FIG. 4

tion; therefore, if long vertical lines are required, the pad may be turned a quarter-turn, which will bring it into such a position that the required lines may be drawn by a horizontal movement. The same procedure may be used in the case of long diagonal lines. Short lines in any direction are more easily and rapidly drawn without turning the pad. As has been said before, the method is less important than the result to be obtained.

10. When the sketcher has learned to draw horizontal and vertical lines, he should next practice combinations of such lines, as shown in Fig. 4 (*c*) and (*d*). Horizontal and vertical lines meet at right angles, and there are innumerable cases, in the sketching of machine details, in which lines must be drawn at right angles, so that it is advisable to become skilful in drawing such lines. The next step is the making of diagonal lines, as shown at (*e*) and (*f*), all of which are formed by a downward movement of the pencil. No great difficulty will be found in drawing lines that slope downwards from right to left, as in (*e*), because ordinary writing makes use of slant lines in this direction, and the hand is already familiar with the necessary movements. But the lines slanting downwards from left to right, as in (*f*), will require considerable practice; moreover, they will be drawn with greater ease and precision if the bottom of the sketch pad is swung slightly to the left, so that the direction of movement of the pencil is squarely toward the body of the sketcher.

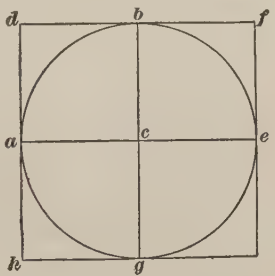


FIG. 5

11. Drawing Curved Lines.—In sketching details of machines, the curved lines to be drawn are usually arcs of circles or complete circles; therefore, the sketcher should accustom himself to the drawing of such curves. If a circle is drawn inside a perfect square, touching all four sides, and the square is divided into four equal smaller squares, as shown in Fig. 5, each quadrant, or quarter of the circle, will lie in a small square and will be tangent to the outer sides of that square. For exam-

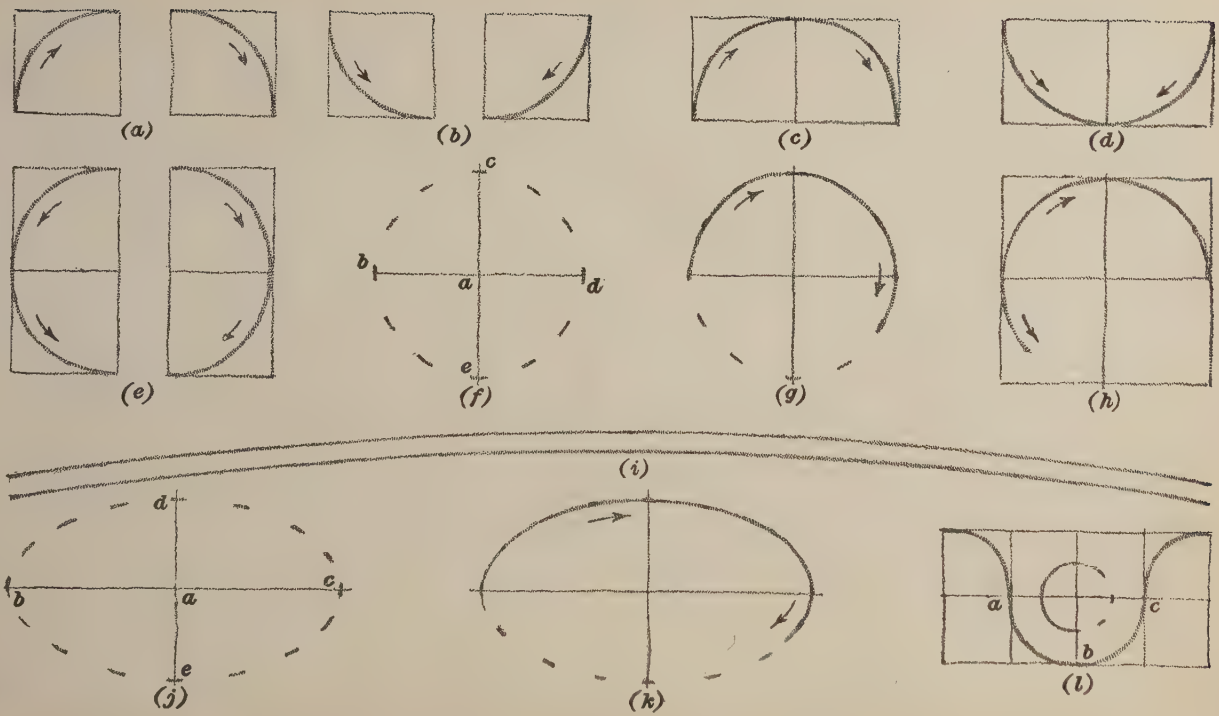


FIG. 6

ple, the quadrant *ab* lies in the small square *acbd* and is tangent to the sides *ad* and *db* at *a* and *b*; and the quarter-circle *be* lies in the small square *bcef* and is tangent to its outer sides *bf* and *ef*. The arc *abe* is a semicircle and is contained in the rectangle *adfe*, which is twice as long as it is high; and the semicircle *bag* is contained in a similar rectangle *dbgh*. The complete circle *abeg* is made up of four equal quarters, or quadrants, that join one another at the middle points of the sides of the large outside square. The foregoing facts are of value because they supply a basis on which to sketch arcs of circles.

12. Examples of freehand drawing of quarter-circles are shown in Fig. 6 (*a*) and (*b*). First, a square of light guide lines is drawn, each side of which has the same length as the radius of the desired arc. Then the curve is drawn from one corner to the diagonally opposite corner. The curve must be so shaped that at the ends it has the same direction as the outer sides of the square. The direction in which the pencil is moved is indicated by an arrow. The drawing of semicircles is shown in (*c*), (*d*), and (*e*). Since a semicircle consists of two quadrants, it is drawn inside a rectangle that is twice as long as it is wide; and if the rectangle is divided into two equal squares, a quadrant may be drawn in each, so that the construction of the semicircle consists in drawing quadrants in two adjacent squares. The lines that outline the squares are used only as guide lines and should be drawn very lightly.

13. One method of drawing a circle freehand is to make use of the fact that all points on the circumference are at the same distance from the center of the circle. Suppose that *a*, Fig. 6 (*f*), is the point at which the center of the desired circle is to be located. Through this point a horizontal and a vertical line are drawn, and on these lines the points *b*, *c*, *d*, and *e* are marked, at a distance from *a* equal to the radius of the circle to be drawn. These points are located by eye, and not by measurement. At first, some difficulty may be found in getting the distances *ab*, *ac*, *ad*, and *ae* about equal; but continued practice will enable the sketcher to lay off these distances with all the accuracy that is required in a sketch. Between the points

thus located, other points should be marked, as shown, all at the same distance from the center. The larger the circle to be drawn, the greater should be the number of additional points. Then the circle is formed by drawing a curved line through the successive points, as shown in (*g*). Another method of drawing a circle is shown in (*h*). A square is outlined in light lines, with its sides equal in length to the diameter of the circle to be drawn. The square is divided into four equal smaller squares, and then a quadrant of the circle is drawn in each small square, just as was done in (*a*) and (*b*).

14. If the curve to be drawn is an arc of a circle having a long radius, a simple way is to use the elbow as a pivot, and, holding the hand rigid, to swing the forearm from left to right in a long sweep. The lines in Fig. 6 (*i*) were drawn by this method.

Another form of curved line that occurs frequently in sketching is the ellipse. This is a figure in which the diameters are unequal, and in which the outline changes its rate of curvature from point to point. An easy method of drawing an ellipse is to block out the curve with points, as shown in (*j*). First, two lines are drawn at right angles to each other. From the intersection *a*, the distances *ab* and *ac* are laid off, each equal to half the long diameter of the required ellipse, and *ad* and *ae* are made equal to half the short diameter, as nearly as can be judged by eye. Then additional points are marked off between *b* and *d*, *d* and *c*, etc., after which a smooth curve is drawn through the points, as shown in (*k*).

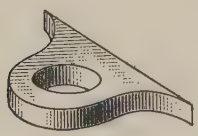


FIG. 7

15. The practice sketch shown in Fig. 6 (*l*) is of a kind that will often be required in machine sketching, because it represents a lug like that illustrated in Fig. 7, through which a bolt may pass to hold a part in place. The sketch, Fig. 6 (*l*), shows how the lug would appear if viewed from a point directly above it. The outline of the lug is made up of a semicircle joined at each end to a quadrant, and the hole in the lug is indicated by a circle having the same center as the semicircle. An easy way

to draw this is to construct a rectangle of light lines, twice as long as wide, and divide it into eight equal squares. The outline of the lug is formed by drawing quarter-circles in four of the small squares, using the methods already described. It should be noticed that these quadrants meet smoothly, without forming angles, at the points *a*, *b*, and *c*. The circle at the center of the lug is drawn by the method previously described.

16. Practice Exercises.—Skill and accuracy in making sketches come only with continued practice, and so there cannot be too much emphasis placed on the necessity for learning how to handle the pencil with ease and smoothness. One exercise that will aid in giving control of the pencil is shown in

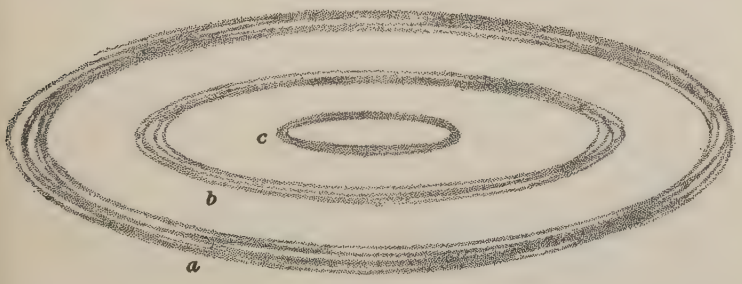


FIG. 8

Fig. 8. The largest ellipse *a* is made by making the hand and wrist practically rigid and swinging the whole forearm so as to guide the pencil in the necessary path. The weight of hand and forearm is carried lightly on the little finger and the fleshy part of the forearm. The direction of motion of the pencil is from right to left in the upper half of the ellipse. The next smaller ellipse *b* is drawn in like manner, but with a smaller sweep of the hand and forearm. The smallest ellipse *c* is made with little or no forearm movement, the wrist and the fingers being flexed or bent just enough to make the pencil trace the curve.

17. Practice in the drawing of vertical and diagonal straight lines is indicated in Fig. 9 (*a*), (*b*), and (*c*). The pencil is held in the fingers in about the same position as for writing, but the hand is bent inwards slightly at the wrist when

drawing vertical lines. The direction of movement of the pencil is indicated by the arrow, and the pencil is lifted from the paper on the upward stroke. In drawing the diagonal lines

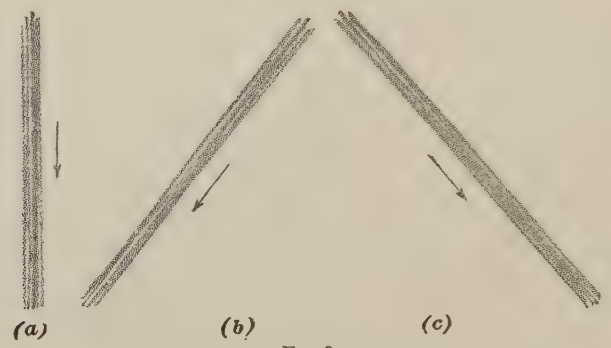


FIG. 9

downwards from right to left, as in (*b*), the hand is tilted to the right somewhat, so that the whole length of the little finger rests against the paper. In drawing the diagonal lines in (*c*), the hand must be bent inwards considerably at the wrist. In all three cases, the movement of the pencil is obtained wholly by flexing the fingers, without moving the arm.

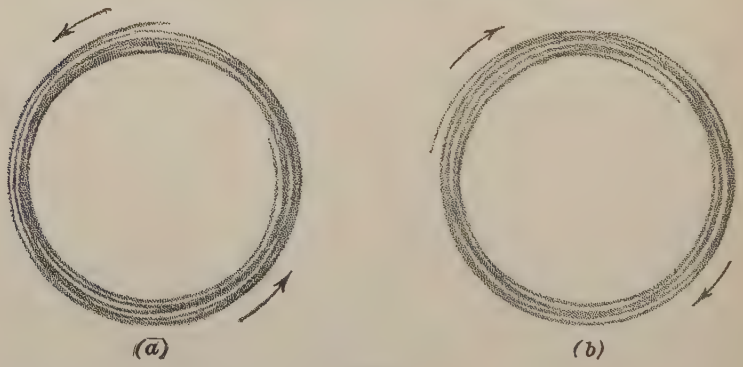


FIG. 10

Practice of the exercises shown in Fig. 10 (*a*) and (*b*) will aid in the drawing of smooth, uniform arcs of circles. In each of these cases, the pencil movement is the result of a combination of swinging the forearm and flexing the fingers.

18. If a sketch is to be begun by drawing a circle to represent the outline of some cylindrical part, the circle may be constructed by any one of the methods previously described, or

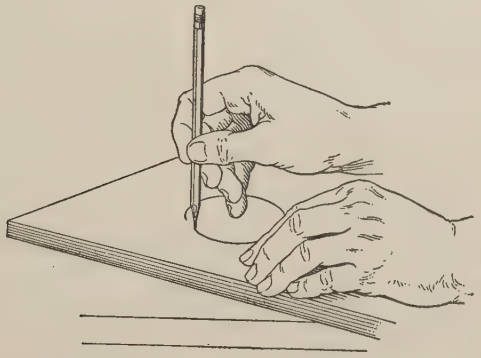


FIG. 11

it may be drawn by the method illustrated in Fig. 11. The sketch pad rests on the knee or on some flat surface. The pencil is held nearly perpendicular to the surface of the paper, between the thumb and first two fingers, the point extended to a distance depending on the size of circle to be drawn. The nail of the little finger acts as a pivot and rests at the point selected as the center of the desired circle. With the pencil thus held, its point is pressed against the paper and the whole pad is rotated by the left hand. The turning of the pad under the nail of the little finger will produce an accurate circle.

If a long straight line such as a center line is to be drawn near one edge of the pad, the edge may be used as a guide, as shown in Fig. 12. The pencil is held in the manner already described, but the third finger is allowed to project down alongside the edge of the pad. Then the whole hand is drawn toward the body, with the pencil pressed against the paper and the third finger sliding along the edge of the pad.

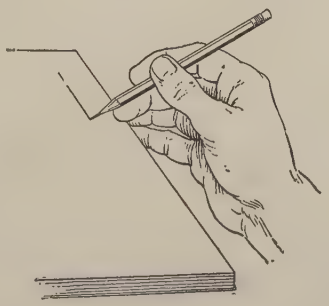


FIG. 12

EXAMPLES OF SKETCHING

PIECES SHOWN BY SINGLE VIEWS

19. Square Washer.—If a piece is simple in form, a single view will often be sufficient to tell all that needs to be known about it. Suppose, for example, that a sketch is to be made of the steel washer shown in Fig. 13, which is $2\frac{1}{2}$ inches square and $\frac{3}{8}$ inch thick and has a $1\frac{1}{4}$-inch hole in the center. The most important features of the washer are that it is square and that it has a central hole; therefore, the sketch should show these. The first step is to draw a square, as *abcd*, Fig. 14, to represent the outline of the washer. The hole is to be at the center of the washer, and this center is found by drawing the light diago-

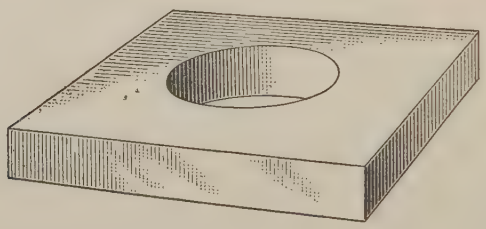


FIG. 13

nals *ac* and *bd* and noting the point *e* where they cross. The diameter of the hole is half the length of a side of the washer, and so the radius of the hole is one-fourth the length of a side of the square. On the sketch, therefore, marks *f* are made at a distance from *e* equal to half the distance from *e* to the *sides* of the square, and a circle is drawn through these points. The circle then represents the hole in the washer. The sketch thus made shows what the washer looks like when viewed from a point directly above it, and is called a *plan*, or *top view*, of the washer.

20. The square and the circle in the sketch, Fig. 14, show the general form of the washer, but the dimensions of the piece must be added before the sketch can be considered complete. The dimensions are put on the sketch by using figures and what are called *dimension lines*. Short *extension lines* are drawn

outwards at *a*, *b*, and *c*, at right angles to *ab* and *bc*, and between them are drawn light dimension lines parallel to *ab* and *bc*. Gaps are left in the dimension lines, and in the gaps are inserted the figures that denote the lengths of the sides of the washer. The figures are followed by the sign ″, which means *inch* or *inches*. Arrowheads are placed at the ends of each dimension line, touching the short extension lines, to indicate the extent of the length to which the dimension refers. A dimension line is drawn across the center of the circle, and $1\frac{1}{4}$″ is inserted, as

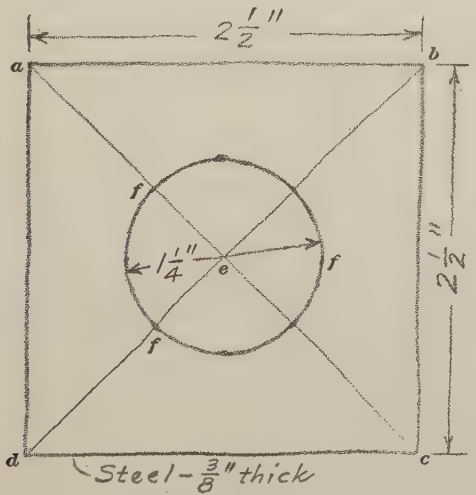


Fig. 14

the hole is $1\frac{1}{4}$ inches in diameter. The note *Steel* is written or lettered on the sketch to indicate the material of which the washer is to be made; and since the thickness is $\frac{3}{8}$ inch at all points, the additional note $\frac{3}{8}$″ *thick* is given. This completes the sketch, as the single view and the accompanying notes give full information as to the shape and dimensions of the washer.

21. **Stop-Pin.**—Another example of a machine part that can be sketched in a single view is given by the stop-pin illustrated in Fig. 15. It consists of a head *a* $1\frac{1}{2}$ inches in diameter and $\frac{5}{16}$ inch thick and a shank *b* 2 inches long and $\frac{7}{16}$ inch in diameter, the shank being central with respect to the head. The

sketch of such a pin should indicate that the head and the shank are round and should show their diameters and thickness or length. Suppose that the pin is held at arm's length in front of the eyes and viewed squarely from the side. It will have the outline of two rectangles, as shown in the sketch, Fig. 16. The rectangle *abcd* indicates the head of the pin, *ab* being the thickness and *bc* the diameter. The rectangle *efgh* indicates the shank, *ef* being the length and *fg* the diameter. The two rectangles have a common center line, because the shank of the pin is central with respect to the head. Thus, the freehand sketch of the pin would consist of two rectangles joined as shown in the illustration.

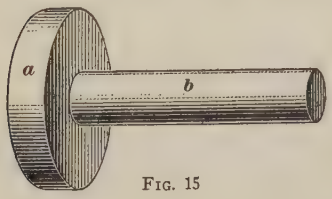


FIG. 15

22. The sketch in Fig. 16 gives all the necessary information regarding the piece, after the dimensions are added. The dimension $\frac{5}{16}''$ denotes the thickness of the head and the dimension 2″ denotes the length of the shank. The diameter of the head is indicated by $1\frac{1}{2}''$ *dia.* and that of the shank by $\frac{7}{16}''$ *dia.*

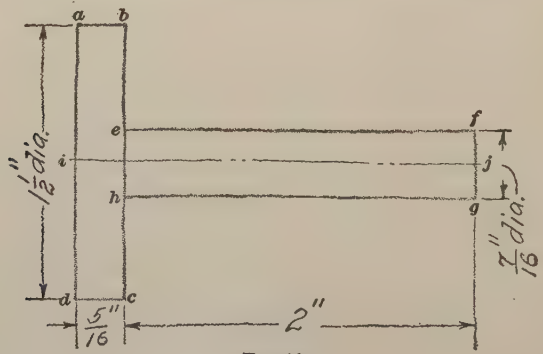


FIG. 16

The addition of *dia.*, meaning *diameter*, is very important in the case of the last two dimensions, because it definitely indicates the shape. Whenever the abbreviation *dia.*, or sometimes *d.* or *diam.*, is added to a dimension, it denotes that the part is

circular in form. In the illustration, if *dia.* had been omitted, there would have been nothing to tell the shape of the head; for a square head measuring $1\frac{1}{2}$ inches on a side, or an elliptical head measuring $1\frac{1}{2}$ inches on one diameter, would be represented by the same rectangle *abcd*. But the addition of *dia.* at once fixes the shape of the part. The view shown may be called a *side view*, because it shows the piece as seen squarely from one side; but it is also a plan, or top view, because the piece would have the same appearance if viewed from a point squarely above it. The dimension $\frac{7}{16}''$ *dia.* is written to one side, and connected by a lead line to the gap in the dimension line, because the gap is too small to contain it easily.

23. Bolt.—The bolt shown in Fig. 17 is another example of a piece that may be sketched in a single view. The body *a* is 1 inch in diameter and $1\frac{1}{4}$ inches long and the head *b* is hexagonal, $\frac{3}{4}$ inch thick and $1\frac{3}{4}$ inches across corners. The threaded end *c* is $\frac{3}{4}$ inch in diameter and $\frac{7}{8}$ inch long and is threaded with National Coarse Thread Series, Class 2 (Free) Fit of which there are ten to the inch. Between the body of the bolt and the threaded part, the bolt is necked to a diameter of $\frac{5}{8}$ inch by a groove *d* $\frac{1}{8}$ inch wide. The piece is of steel and is finished all over.

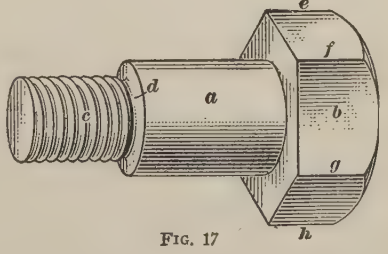


FIG. 17

24. To illustrate the use of cross-section paper in sketching, the sketch of Fig. 17 will be described as though it were made on such paper. As the bolt is a long cylindrical piece, the sketch may be begun by drawing a light center line *ab*, Fig. 18, to follow one of the lines on the squared paper. Each square on the sketch pad is $\frac{1}{8}$ inch on a side, and so the sketch may be drawn full size; that is, the dimensions of the sketch may be those of the bolt itself. On each side of the center line, and parallel to it at a distance of four squares, or $\frac{1}{2}$ inch, draw the lines *cd* and *ef*, making each $1\frac{1}{4}$ inches long, which corresponds to 10 squares; then draw the straight lines *ce* and *df*, completing

the rectangle *cdfe*, which will represent the body of the bolt. At a distance of one square, or $\frac{1}{8}$ inch, from *ce* draw the vertical line *gh* to represent one end of the threaded part. As the threaded part is $\frac{3}{4}$ inch in diameter, the points *g* and *h* are $\frac{3}{8}$ inch, or three squares, on each side of the center line. The length of the threaded part is $\frac{7}{8}$ inch, and so the horizontal lines *hi* and *gj* are made seven squares long and *ij* is drawn.

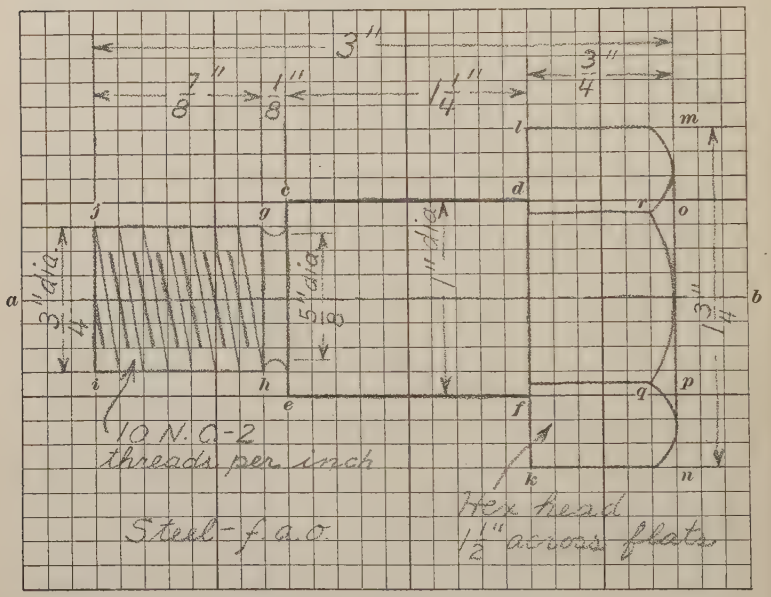


Fig. 18

25. The groove, or neck, between the body of the bolt and the threaded part, Fig. 18, is $\frac{1}{8}$ inch smaller in diameter than the threaded part and is $\frac{1}{8}$ inch wide; so, in the sketch, it is represented by drawing semicircles from *g* to *h* to join the line *ce*, the radius of these semicircles being $\frac{1}{16}$ inch, or half the width of a square. The threads on the end of the bolt are indicated by what is called a *conventional method*, which consists of a series of slanting lines that are alternately light and heavy. The light lines extend from the line *jg* to the line *ih*, but the heavy lines touch neither. These lines should slope

downwards from right to left when the center line *ab* of the bolt is vertical. They then indicate that the thread is right-hand. The form of the thread and the number of threads per inch are given by adding the note *10 N.C.-2 threads per inch.* If a piece is threaded with left-hand threads, as sometimes happens, the note should state clearly that the threads are left-hand. If no such note is placed on the sketch, it is always assumed that the threads are right-hand.

26. The hexagonal head of the bolt remains to be sketched. To do this, the line *df,* Fig. 18, is extended in opposite directions from *d* and *f* to *k* and *l,* making *kl* equal to the distance across corners of the bolt head, which is $1\frac{3}{4}$ inches; and this means that *k* and *l* are $\frac{7}{8}$ inch from the center line, or 7 squares from it. As the thickness of the head is $\frac{3}{4}$ inch, the horizontal lines *lm* and *kn* are made six squares long, and *mn* is drawn. The bolt in Fig. 17 is viewed from a point squarely opposite the side, and in this position the edges *e, f, g,* and *h* of the head can be seen, so these must appear on the sketch. The conventional method of showing a hexagonal head or nut is indicated in Fig. 18. The lines *cd* and *ef* are continued till they meet *mn* at *o* and *p,* respectively. Between the lines *lm, do, fp,* and *kn* arcs of circles are drawn, touching *mn,* these arcs meeting at the points *q* and *r.* The lines *lm, do,* etc., represent the edges of the head and the arcs indicate that the upper corners of the head are chamfered, or beveled.

27. The sketch in Fig. 18 is completed by adding the necessary dimensions and explanatory notes. The body, the neck, and the threaded part of the bolt are cylindrical, and so the abbreviation *dia.* is added to the dimension of each part to indicate that the cross-section is circular. To make certain that there shall be no misunderstanding as to the shape of the head, the note *Hex. head* is given. The distance across flats, or between parallel sides of the head, is $1\frac{1}{2}$ inches. It will be observed that the total length of the bolt, including the thickness of the head, is marked on the sketch. This dimension, 3 inches, is the sum of the dimensions of the several parts and is called the *overall dimension.* It is of value because it shows

the mechanic at a glance the length of stock required to make the bolt. Whenever an overall dimension is given, care should be taken to see that it checks correctly with the partial dimensions that compose it. The abbreviation *f.a.o.* means *finish all over* and indicates that every surface of the bolt is to be finished.

28. Size of Sketch.—Before a sketch is begun, it is necessary to decide about what size it is to be drawn; that is, the sketcher should form some idea of the approximate scale to which the sketch will be made. Of course, it should be clearly understood that an accurate scale drawing is not possible in sketching. The best that can be done is to come as close to the relative dimensions as the ability of the sketcher will allow. In any case, the result will be only roughly approximate. If the piece to be sketched is of such dimensions that a full-size sketch cannot be drawn on the pad, a sketch one-half, or one-third,

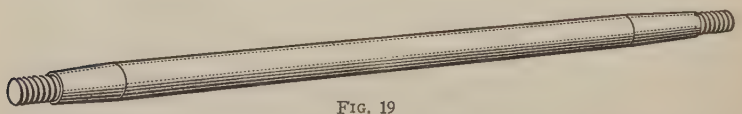


FIG. 19

or some other fraction of full size may be chosen. If it is decided to make the sketch half-size, then the various parts of the piece will be shown on the sketch approximately half their size on the actual piece.

If a piece is very small, so that there would be difficulty in writing the necessary dimensions on a full-size sketch, it may be drawn to an enlarged scale; that is, the sketch may be 2, 3, 4, or more times as large as the actual piece. No matter what scale is used, however, the dimensions marked on the sketch must be the actual full-size dimensions of the piece. The views should not be crowded on the sheet. If they cannot conveniently be put on the same sheet, separate sheets should be used for the different views.

29. Piston Rod.—A piston rod for an engine is illustrated in Fig. 19. It is 32 inches long and 2 inches in diameter between the tapered sections. Each of the tapered parts is 4 inches long and tapers $\frac{3}{4}$ inch per foot, so that the diameter at the small end

of the taper is $1\frac{3}{4}$ inches. The threaded section at each end is $1\frac{1}{2}$ inches in diameter and 2 inches long and has 6 threads per inch. If a sketch of this rod is made approximately one-fourth full size, it will be about 11 inches long, since the total length of the piece is 44 inches. However, it is not necessary to draw the piece in full. When a part is of uniform shape and size through a considerable distance, as in the case of this shaft, the work of sketching may be reduced by omitting a part of the uniform section of the piece, as shown in the sketch, Fig. 20. The omission is indicated by what is called a *break,* and the form of break shown is the usual way of denoting the omission of part of a cylindrical piece. Wherever a break is used, it may always be assumed that the part omitted has the same diameter

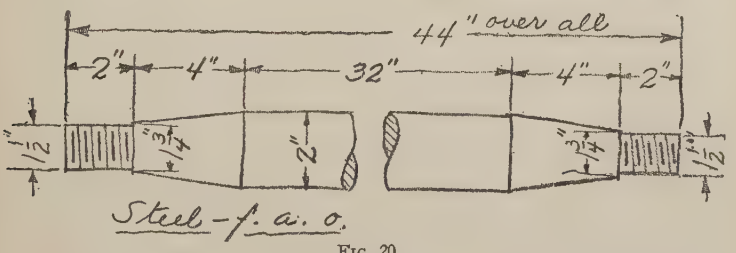


FIG. 20

as the parts on both sides of the break. It is to be noted, also, that even though a part is broken out, the dimension given is the full length of the unbroken piece.

PIECES SHOWN BY TWO VIEWS

30. Stuffingbox Gland.—Some parts of machines are of such construction that their shape and dimensions cannot be shown in single views. In such cases the sketches must contain two or more views of the pieces. The stuffingbox gland illustrated in Fig. 21 is an example of a piece that requires at least two views. It is used to compress the packing around a reciprocating or rotating rod, and thus prevent leakage of fluid along the rod. The rod passes through the opening *a*, which extends clear through the piece and is $\frac{3}{4}$ inch in diameter. The part *b* that extends into the stuffingbox is $1\frac{1}{4}$ inches in diameter and 1 inch long. The flange *c* is $\frac{3}{8}$ inch thick and approximately oval

in form. Its greater diameter is $2\frac{3}{4}$ inches and its smaller diameter is 2 inches. The $\frac{5}{16}$-inch bolt holes d are equally spaced on opposite sides of the central opening and their centers are $2\frac{1}{4}$ inches apart. The outer curved surfaces e are concentric with the bolt holes and the radius of each is $\frac{3}{8}$ inch. The curved surface f and the corresponding one at the other side of the flange are concentric with the hole a and so the radius of each is 1 inch. The surfaces h that join the curved faces e and f are flat surfaces. The end of the part b is chamfered inwards so that the surface g makes an angle of 30 degrees with the end. With this information, and the illustration shown, a sketch of the piece may be drawn.

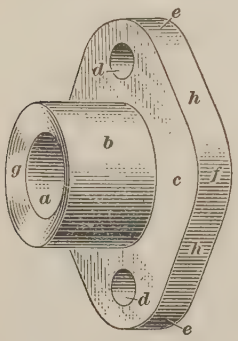


FIG. 21

31. The gland shown in Fig. 21 is symmetrical with respect to the horizontal center line through the center of the opening a; that is, the halves on opposite sides of this line are alike. So it is wise to start the sketch by drawing a horizontal center line, as ab, Fig. 22 (a), it being assumed that a side view of the piece is to be sketched first. The cylindrical part of the gland is 1 inch long and $1\frac{1}{4}$ inches in diameter, and as these dimensions are very nearly alike, the part will be represented on the sketch by a rectangle $cdef$ in which cd is slightly shorter than cf. The distance of cd and ef from the center line is half the diameter of the part, or $\frac{5}{8}$ inch. When the piece is viewed from the side, only the edge of the flange can be seen, and this will appear as a rectangle $\frac{3}{8}$ inch wide and $2\frac{3}{4}$ inches long, that joins the cylindrical part represented by $cdef$. The line de is extended at the ends to g and h, so that the distance from the center line to g or h is $1\frac{3}{8}$ inches, or half the long dimension of the flange. Next, two horizontal lines gi and hj are drawn from g and h, and each is $\frac{3}{8}$ inch long. Finally, the line ij is drawn; as gi and hj are equal, ij is parallel to gh.

32. The side view, Fig. 22 (a), is not enough to give all the necessary information regarding the gland, because it does

not show the shape of the flange. From that view alone, the flange might be round, square, or oval; hence, it is necessary to make a second view, and this view must show the piece as it appears when seen from another angle. It is customary to draw the views as though the piece were seen in directions at right angles to each other. Thus, if the side view (*a*) shows the piece as viewed from the front side, the second view would be taken at right angles to this and would show the piece as it would look if viewed from the end. Such a view is called an end view, and is shown in (*b*). In this case the right end is taken, and so the end view is placed to the right of the side view. If the view were taken from the left end of the piece, it would be placed at the left of the side view. This is the rule followed

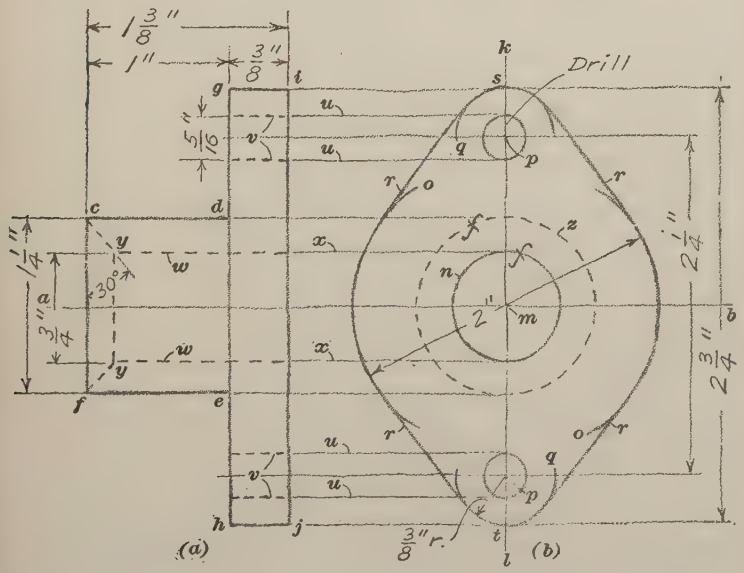


Fig. 22

in the United States. In Europe, however, the right-hand view is placed at the left of the front view and the left-hand view at the right of the front view.

33. The flange of the gland is symmetrical with respect to the center line *ab*, Fig. 22, but it is also symmetrical with

respect to a center line drawn through the centers of the bolt holes. So, to construct the end view (*b*), draw the light vertical center line *kl*, which will cross *ab* at right angles at *m*, and this point will represent the center of the hole in the gland. As the hole is $\frac{3}{4}$ inch in diameter, a circle *n* is drawn with *m* as a center and with a radius of $\frac{3}{8}$ inch, and this circle represents the opening in the gland. The curved surfaces *f*, Fig. 21, have a radius of 1 inch; so, in Fig. 22 (*b*), arcs *o* are drawn on opposite sides of the center *m* with a radius of 1 inch. The centers of the bolt holes are $2\frac{1}{4}$ inches apart, which means that each is $1\frac{1}{8}$ inches from the center line; hence, the points *p* are located at a distance from *m* nearly equal to the distance *cf*, view (*a*), which represents $1\frac{1}{4}$ inches. Then, with the points *p* as centers, circles $\frac{5}{16}$ inch in diameter are drawn to represent the bolt holes. The curves *e*, Fig. 21, have the same centers as the bolt holes and the radius of each is $\frac{3}{8}$ inch; so the arcs *q*, Fig. 22 (*b*), are drawn with a radius equal to the distance *gi*, view (*a*), as this distance represents $\frac{3}{8}$ inch. Finally, straight lines *r* are drawn tangent to the arcs *o* and *q*, thus completing the flange.

34. The distance *ij*, Fig. 22 (*a*), represents the longer diameter of the flange of the gland; but the distance *st*, view (*b*), is also the longer diameter. If the end view has been properly drawn, therefore, *st* should equal *ij*; in other words, if the lines *gi* and *hj*, view (*a*), are extended to the right as indicated by the light lines, they should meet the center line *kl*, view (*b*), at *s* and *t*. This is an important point, because it furnishes a means by which certain details in one view can be found from the same details in the other view. For example, suppose the positions of the bolt holes are to be indicated in the side view (*a*). All that is necessary is to draw light horizontal lines *u*, parallel to the center line *ab*, from the top and bottom of the circles that represent the bolt holes and extend them to the left until they cut across the side view (*a*). The short dotted lines *v* then represent the positions of the bolt holes in the side view. The light lines *u* are called *projectors,* or *projection lines,* because they serve to project, or transfer, a detail in one view to its corresponding position in another view.

35. It should be observed that the lines *v*, Fig. 22 (*a*), are drawn dotted for a very good reason. It is a rule in drawing that any detail which cannot be seen by the eye of the sketcher, but which is shown in the sketch, must be indicated by dotted lines instead of full lines. When the gland in Fig. 21 is viewed squarely from the side, the bolt holes *d* cannot be seen by the sketcher, for they are inside the solid material of the flange. But their positions can be indicated in the side view, Fig. 22 (*a*), by drawing the dotted lines *v* as already explained. Each pair of lines *v* represents the top and bottom of a bolt hole. These dotted lines extend only between the lines *gh* and *ij* that represent the inner and outer faces of the flange, because the bolt holes run through the flange from one face to the other. In the end view (*b*), the circles that represent the bolt holes are drawn in full lines, because, when the gland in Fig. 21 is viewed from a point to the right, the outlines of the bolt holes are clearly seen by the sketcher; that is, they are not hidden by solid metal. The same is true of the central hole in the gland, and hence the circle *n*, Fig. 22 (*b*), is made a full line and not a dotted line.

36. When the gland in Fig. 21 is viewed from the side, the central hole *a* cannot be seen by the sketcher, as it is hidden by the solid metal of the part *b*; therefore, if the position of this hole is shown in the side view, Fig. 22 (*a*), it must be done by dotted lines, as at *w*. The position of these lines is easily found by projection from the end view (*b*). The circle *n* represents the central opening in that view; so, projectors *x* are drawn from the top and bottom of the circle *n* and are extended to the left across the side view. The dotted lines *w*, view (*a*), do not extend to the line *cf*, because the central hole does not extend that far, on account of the beveling of the end. The bevel is 30 degrees, and so lines are drawn from *c* and *f* at 30 degrees to the vertical, and the lines *w* end at the points *y* where they cut the slanting lines from *c* and *f*. The lines *cy* and *fy* represent the beveled surface, and as it cannot be seen when the piece is viewed from the side, these lines also are drawn dotted. The circle *z*, view (*b*), represents the outer surface of the part *b*, Fig. 21, which is hidden behind the flange *c* when the piece is

viewed from the right-hand end; therefore, this circle is dotted. Its position may be obtained by projection lines from the points *d* and *e*, Fig. 22 (*a*), since *de* represents the diameter of the part *b*, Fig. 21.

37. The sketch in Fig. 22 is completed by putting on the necessary dimensions, as shown. There are some points in which the dimensioning of sketches that consist of two views differ from those in which there are only single views. For instance, it will be seen at once that the dimensions of circular or cylindrical details omit the abbreviation *dia.* after the dimensions. The reason is that the circles in view (*b*) show that the details are circular; hence, as there is no doubt about their shape, the dimensions alone are sufficient. In a sketch having but one view, however, there is no circle to indicate a cylindrical part, and so the abbreviation *dia.* is needed. The dimension $\frac{3}{8}''$ *r.* is the usual way of indicating that a curved part, such as the end of the flange, has a radius of $\frac{3}{8}$ inch. The arrowhead indicates the arc and the inner end of the arrow designates the center *p* from which the arc is drawn. The bevel at the small end of the gland is indicated in view (*a*) by extending a light line from *cy* and writing 30° between it and *cf*, thus indicating that the beveled surface is at 30 degrees to the end of the gland.

38. Finish Marks.—If any of the surfaces of a piece are to be machined, they are indicated on the sketch by the use of the *finish mark*. This consists of a letter *f* written on the line that denotes the surface to be machined, and the *f* should be so made that its cross-line crosses the line designating the machined surface. In the case of the gland in Fig. 21, the central hole *a* and the outside of the part *b* are to be machined. In Fig. 22 (*b*), the surface of the central hole is denoted by the circle *n*, and so a finish mark is placed on this circle. The outer surface of the body of the gland is denoted by the dotted circle *z*, and a finish mark is placed on it, also.

39. Practical Suggestions.—In making a sketch, it will be found an excellent plan to draw all lines lightly, whether they

represent center lines, projection lines, or outlines of the piece being sketched. Lines so drawn are easy to erase in case errors are made. After the sketch is completed, those lines that mark the outline of the piece may be made heavier by going over them again and putting pressure on the pencil; or they may easily be converted to dotted lines by the same method. This practice has been followed in making the sketches shown in this Section.

In drawing lines on the sketch pad, it is important to keep the point of the pencil always in sight; that is, no line should be attempted with the pencil in such a position that the point is hidden by the hand. An accurate line cannot be drawn under such conditions. As stated before, the pad may be turned to any position that will make the work of sketching easier. Particularly in drawing curves it is necessary to be able to see not only the part of the line that has been drawn but also the point to which it is being drawn.

FIG. 23

40. Crank.—The piece shown in Fig. 23 is a crank, the arm *a* of which is $1\frac{1}{2}$ inches thick. At the larger end it has a boss *b* 5 inches in diameter, the surface of the boss being $\frac{3}{4}$ inch above the surface of the arm. In the center of the boss is a square hole *c*, measuring 2 inches on a side, that extends through the piece. At the small end is another boss *d*, 2 inches in diameter, but on the opposite side of the arm, and this boss is $\frac{1}{2}$ inch above the surface of the arm. A hole *e* $1\frac{1}{4}$ inches in diameter is drilled through the crank at the center of the small boss. The sides of the arm are straight, giving a uniform taper to the crank. The distance between the centers of the holes *c* and *e* is 12 inches. It will be observed that the side of the boss *b* does not meet the surface of the arm *a* at a sharp angle, but that a smooth curve *f* of small radius joins the two. This filled in portion is known as a *fillet*. Fillets are used extensively to avoid the weakness caused by sharp corners.

41. The sketch of the crank in Fig. 23 is most easily begun by drawing a top view of the piece, as shown in Fig. 24 (*a*). The first thing to do is to decide on the approximate scale to which the sketch is to be drawn. It is not feasible to draw it full size, and even if it is drawn half size some of the lines will be rather long; consequently, the sketch will be made about one-fourth size.

As the piece is symmetrical with respect to a line between the centers of the holes, the horizontal center line *ab* is drawn first,

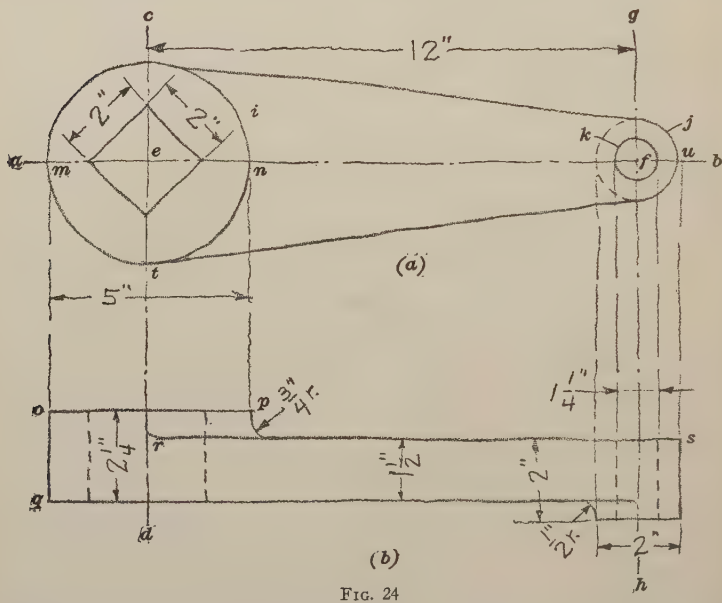


FIG. 24

this being a light pencil line. Near one end the light vertical center line *cd* is drawn, cutting *ab* at *e*, and *e* may then be taken to represent the center of the square hole. Next, the point *f* is located, representing the center of the round hole in the small end of the crank. As the distance between the centers of the holes is 12 inches, and the sketch is to be one-fourth the full size, the point *f* is located at a distance from *e* equal to $12 \div 4 = 3$ inches, as nearly as can be judged by eye. Through *f* the vertical center line *gh* is drawn.

42. As the point *e*, Fig. 24 (*a*), denotes the center of the large boss of the crank, which is 5 inches in diameter, the next step is to draw a circle, with *e* as a center, to represent this boss as seen from a point well above the crank. To a scale of one-fourth, this circle *i* will be $1\frac{1}{4}$ inches in diameter and will have a radius of $\frac{5}{8}$ inch. Points are marked on the lines *ab* and *cd*, at a distance of $\frac{5}{8}$ inch from *e* and a circle is drawn through them, as already described. At the other center *f* a circle *j* $\frac{1}{2}$ inch in diameter is drawn to represent the small boss. The outer semicircle coincides with the shape of the upper surface of the arm and so is a full line; but the inner semicircle is dotted because it represents that edge of the small boss which is hidden from view when the piece is looked at from above. When these circles have been drawn, the outline of the crank is completed by drawing straight lines tangent to the circles. A circle *k* is drawn to represent the hole in the small end of the crank. A square $\frac{1}{2}$ inch on a side must be drawn at the center of the circle *i* to represent the square hole. The corners of the square must lie on the center lines *ab* and *cd*.

43. The top view, Fig. 24 (*a*), is not sufficient because it fails to show the thickness of the crank or the height of the bosses; therefore, the front view (*b*) is added, which shows the crank as seen from a point directly in front of it. This view is obtained by drawing projection lines from the top view. First, projection lines are drawn from *m* and *n* at right angles to *ab*, and between them is drawn the horizontal line *op* that represents the upper face of the large boss. As this boss is $\frac{3}{4}$ inch above the surface of the arm, the thickness of the heavy end of the crank is $\frac{3}{4}+1\frac{1}{2}=2\frac{1}{4}$ inches. So the vertical line *oq* is drawn to represent a length of $2\frac{1}{4}$ inches. Then a horizontal line is drawn from *q* to the right, to represent the under face of the crank. Below *op* a distance representing $\frac{3}{4}$ inch, to scale, the horizontal line *rs* is drawn, which is the upper face of the arm. The point *r* is vertically below the point *t* where the flat side of the arm meets the curved large end, and the point *s* is vertically below the end *u* in the top view. The boss at the small end in the front view is drawn in the same manner as was the large

boss. The fillets for the bosses have radii of $\frac{3}{4}$ inch and $\frac{1}{2}$ inch, respectively. The dotted vertical lines that represent the holes in the ends of the crank are located by drawing projection lines from the top view. Finally, the dimensions are marked on the sketch, as shown.

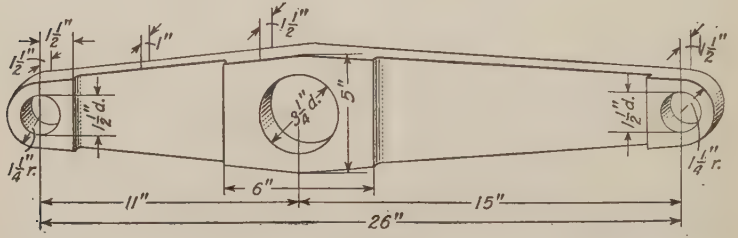


FIG. 25

44. Practice Sketch I.—It is assumed that thus far the student has carefully studied the text, that he has performed the various practice exercises, and that he has drawn freehand sketches of the various machine parts that have been illustrated. If he has done this work conscientiously, he should be able to make a satisfactory sketch of a simple piece. To test this ability, it is suggested that the student, on reaching this point, make a freehand sketch of the lever shown in perspective in Fig. 25, and send it to the Schools for inspection and criticism. It may be drawn on any sheet of convenient size and should be marked "Practice Sketch I." The sheet should carry the student's name, address, and class letters and number. The sketch may be made any convenient size, but it is suggested that it be approximately one-half the full size. It should show a front view and a top view, and all the necessary dimensions should be marked thereon.

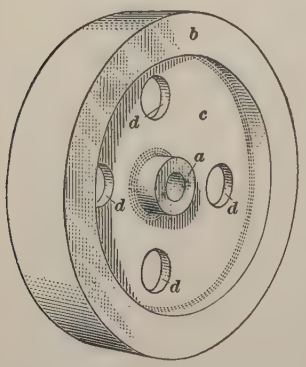


FIG. 26

45. Flywheel.—The piece shown in Fig. 26 is a flywheel cast in one piece, consisting of a hub *a* connected to a heavy

rim *b* by a web *c*, containing four equally spaced holes *d*. The rim is $2\frac{1}{2}$ inches wide and $1\frac{1}{2}$ inches deep, and the outside diameter of the wheel is 12 inches. The outside diameter of the hub is 2 inches, the length is 2 inches, and the bore of the hub is 1 inch. The web is $\frac{1}{2}$ inch thick and the holes *d* are $1\frac{1}{2}$ inches in diameter, their centers being 3 inches from the wheel center.

If the flywheel were sketched in the usual way, showing front and side views, these would appear as in Fig. 27 (*a*) and

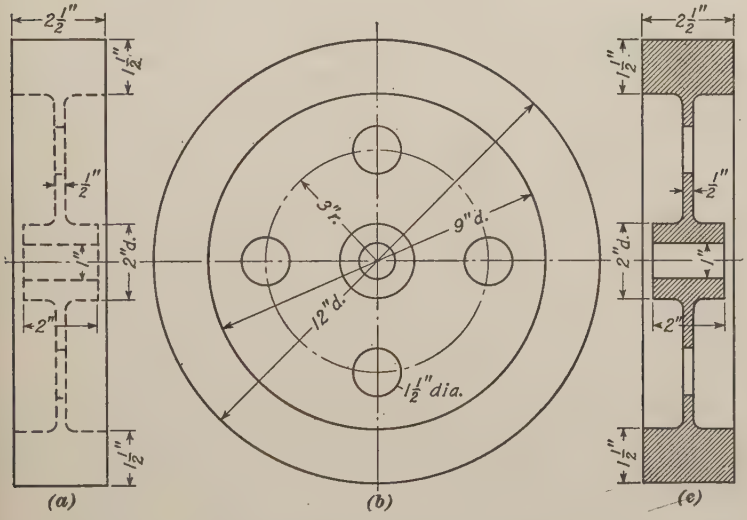


FIG. 27

(*b*). The side view consists wholly of circles shown by full lines, since the outlines of the rim, hub, and holes are all visible when the wheel is viewed from the side. But the front view is made up largely of dotted lines, because the web, inside of rim, hub, and holes cannot be seen when the wheel is viewed edgewise. When a sketch contains a large number of dotted lines, there is always danger of confusing them and making errors. This is particularly true if the dotted lines cross one another or lie close together. It is always preferable to show details by full lines rather than by dotted lines, when this can be done. For this reason, use is made of *sectional views,* also called *cross-sections* or simply *sections.*

46. The method by which a sectional view is obtained may be understood from Fig. 28. Suppose that the flywheel in Fig. 26 is cut in two in a vertical direction and that one half is moved aside, as in Fig. 28, so as to show the surface along which the cut is made. In the illustration, this surface is indicated by a series of short diagonal lines known as cross-section lines, also called section lines, section lining, and cross-hatching. If the half *a* of the wheel is viewed squarely toward the cut surface, and a sketch of it is made, it will appear as in Fig. 27 (*c*), which is therefore a sectional view of the wheel. It will be seen at once that the sectional view has the same arrangement of lines

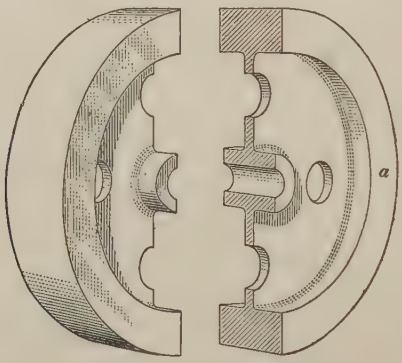


FIG. 28

as the front view (*a*); but the lines in the sectional view are full lines, and the areas that represent a cut through the solid metal of the wheel are cross-sectioned by the short diagonal lines. As a result, the sectional view (*c*) is much clearer than the front view (*a*) with its dotted lines. A sketch consisting of views (*b*) and (*c*) is therefore preferable to one consisting of views (*a*) and (*b*).

47. Arrangement of Dimensions.—Dimensions may be placed on sketches in a great variety of ways, depending on the space available. The usual way is to write the dimension figures at or near the center of the dimension line. But if the dimension is the diameter of a circular part, it is sometimes better to write the dimension away from the center of the line.

An excellent example is shown in Fig. 27 (*b*). Here the inside and outside diameters of the wheel rim are given. If they were placed at the middle points of the lines, one would be on top of the other. To avoid this, they are placed away from the middle, and thus there is no confusion. If the space in which the dimension is to be written is too small to contain the line, the arrowheads, and the figures, the arrows may be placed on the outside, pointing toward each other, with the dimension between, as in the case of the diameter of the bolt hole in Fig. 22 (*a*); or, the dimension may be written at the side, as for the web thickness in Fig. 27 (*c*). Still another way of arranging a dimension is shown in the case of the thickness of the lever in Fig. 25, where $1\frac{1}{2}''$ is written alongside the view and its proper place is indicated by a short line. Dimensions should be so placed that they can be read with the sketch in the usual position or by giving it a quarter-turn to the right.

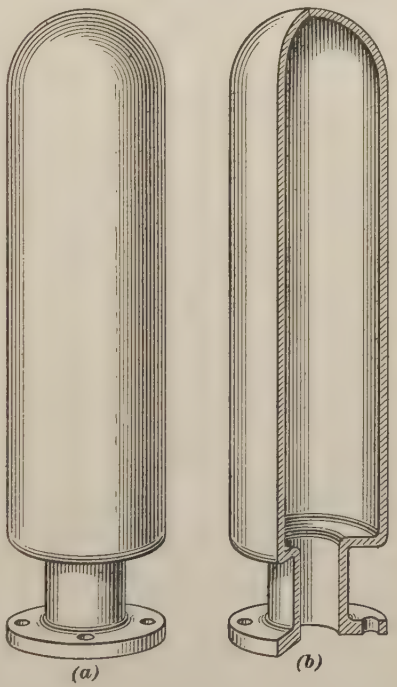


FIG. 29

48. Partial Section. Of course, it is not feasible for a sketcher to cut a machine part in two, as described in Art. 46, for the purpose of obtaining a sectional view. But he can *imagine* a part to be thus divided, and so picture in his mind the appearance of the imaginary cut. Moreover, it is not necessary that the section extend across the piece from one side to the other. It may be taken only partly through, in which case the resulting section is called a partial section.

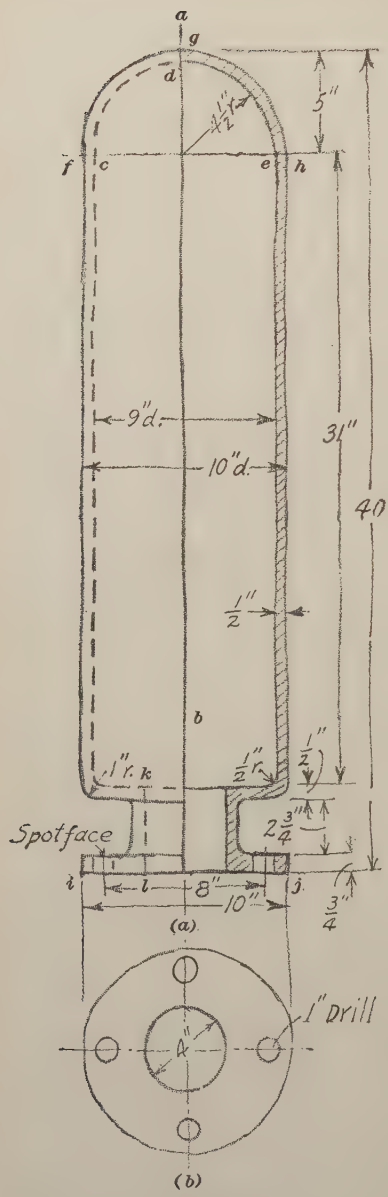


FIG. 30

For example, suppose that a sketch is to be made of the air chamber for a pump, as shown in Fig. 29 (*a*). This is a hollow cylindrical casting $\frac{1}{2}$ inch thick, 9 inches in diameter inside and 40 inches long over all. The upper end is hemispherical and at the lower end is a flange 10 inches in diameter and $\frac{3}{4}$ inch thick, joined to the air chamber by a throat 4 inches in diameter inside and $2\frac{3}{4}$ inches long on the outside. The flange is drilled with four 1-inch holes spaced equally on a bolt circle 8 inches in diameter.

49. As the air chamber in Fig. 29 (*a*) is symmetrical about its vertical center line, its proportions may be shown by a partial section taken along that center line. Suppose that the piece is cut in the manner shown in (*b*), so that one quarter may be removed. If the piece is then sketched as seen from a point straight in front, half of the front view will show the outside of the casting and the other half will show a section. Such a sketch is shown in

Fig. 30 (*a*). It is made by first drawing the vertical center line *ab*, and then the semicircle *cde* with a radius of $4\frac{1}{2}$ inches, or half the inside diameter of the casting. With the same center, but with a radius of 5 inches, the semicircle *fgh* is drawn. The distance between the two semicircles is then $\frac{1}{2}$ inch, or the thickness of the casting. From *f*, *c*, *e*, and *h*, vertical lines are drawn, each 31 inches long, to the scale chosen for the sketch. The bottom line *ij* of the flange is drawn horizontal, at a distance of 40 inches below *g*, and the outline of the flange is completed. Then the throat is drawn, joining the flange and the air chamber. This view is a partial section of the air chamber.

50. Because the left half of the front view, Fig. 30 (*a*), shows the outside of the casting, the line *dckl* that denotes the inside surface must be drawn dotted, for that face cannot be seen. The same is true of the bolt hole in the left half of the flange. On the other hand, the lines in the right half of the sketch are all full lines, because the imaginary removal of the quarter-section of the casting would expose the edges to the view of the sketcher. A bottom view (*b*) is drawn to show the outline of the flange and the location of the four bolt holes in it. These are drilled holes 1 inch in diameter, and the note indicates that fact. The note *Spot face* on the upper side of the flange in view (*a*) indicates that the metal around the upper end of each hole is removed, to form flat surfaces for the nuts or heads of the bolts by which the air chamber is fastened. The diameter of the bolt circle is indicated by a dimension line extending between two extension lines through the centers of opposite bolt holes.

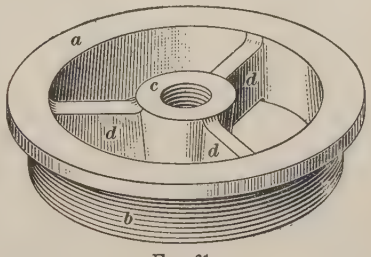


FIG. 31

51. Conventional Sections.—The piece illustrated in Fig. 31 is a seat for a pump valve. It consists of a narrow flange *a* at the top of a ring *b* threaded on the outside and tapered on the inside. A central boss *c* is connected to the outer

ring by three webs *d*. If this piece were sketched, its top view would appear as in Fig. 32 (*a*). Now, if a cross-section were drawn in the usual way, along the center line *ab*, it would appear as in view (*b*). One of the three webs would be shown in section, as at *c*, while the right half of the drawing would show another web by foreshortened lines *d*. Such a section is unde-

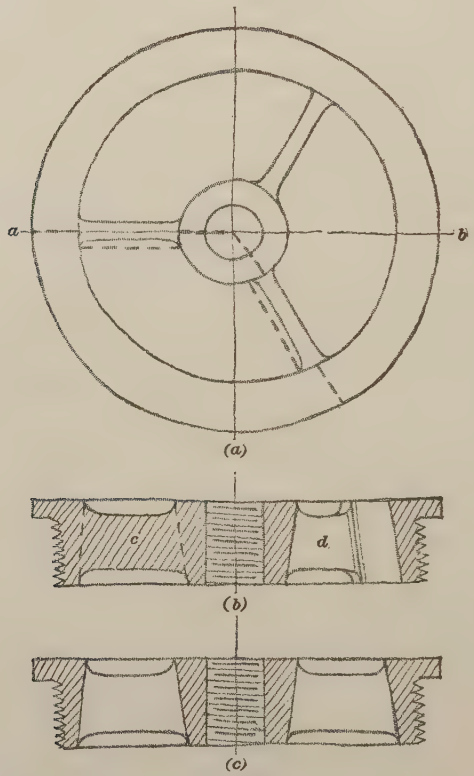


FIG. 32

sirable, because it does not show clearly the construction. The customary way would be to draw the section as shown in (*c*). This shows the section of the outer ring and of the central boss, with the webs joining them. It is called a conventional section, because it is not a true cross-section. It may be considered as a section taken along the heavy dotted line in view (*a*), with

the part to the right of the center swung back into line with the left half. Conventional sections are used in drawing sections of pulleys, flywheels, hand wheels, and similar parts.

52. The shape of the cross-section of a part is sometimes drawn directly on the side view or front view. For example, Fig. 33 (*a*) shows a side view of a cast-iron support that is to span an opening. The end pads *a* and *b* are bolted to adjacent

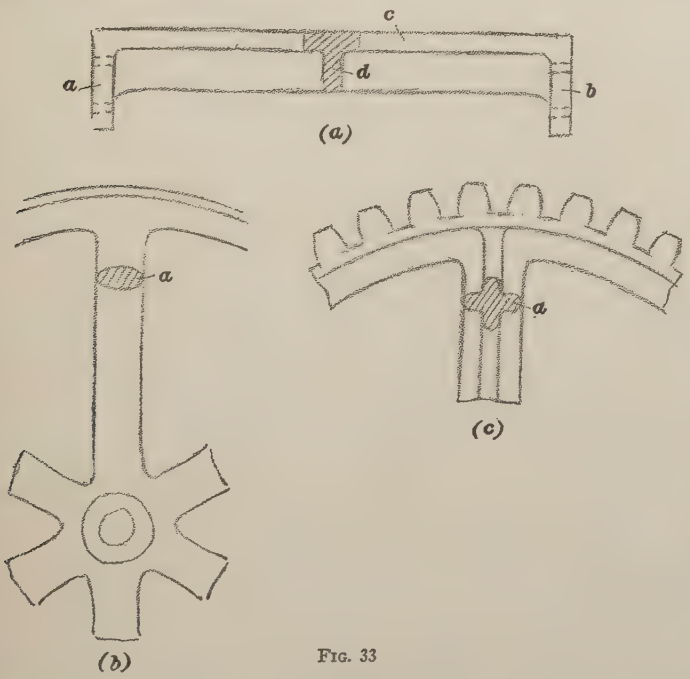


FIG. 33

parts and the central bar *c* supports a load. This bar is of **T** section, as indicated by the conventional section at *d*. In view (*b*) is shown part of a sketch of a cast-iron pulley having arms of elliptical cross-section. The shape of the cross-section is indicated by the ellipse at *a*. A similar example is shown in (*c*), which is part of the rim and one arm of a heavy gear wheel. The section at *a* indicates that the arm has the form of a plus sign, the greater length being in the direction of rotation of the gear.

53. Shaft Coupling.—The device illustrated in Fig. 34 is a shaft coupling, its purpose being to connect two shafts *a* and *b* that are in line. The coupling consists of two parts *c* and *d* that are keyed to the ends of the shafts and that meet along the face *e*. The two are then rigidly joined by six through bolts *f*. The two parts are exactly alike, except that, at the center of the faces where they meet, one has a recess $\frac{1}{8}$ inch deep and 4 inches in diameter and the other has a projection of the same shape and size that fits into the recess. The total length of each half of the coupling, from the face *g* of the hub to the

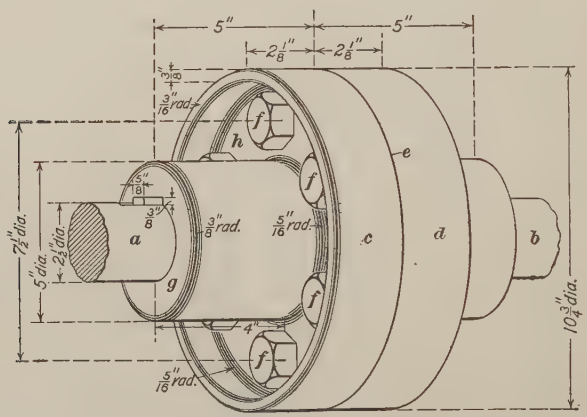


Fig. 34

face *e* along which the halves meet, is 5 inches. The thickness of each half at the point *h* is 1 inch. The bolts are 1 inch in diameter, with standard hexagonal heads and nuts. The keys by which the halves of the coupling are fastened to the shafts are $\frac{3}{8}$ inch by $\frac{5}{8}$ inch in section. The other dimensions are given in the illustration. A sketch of the coupling is required. Because there are many details inside the flanges, it is wise to draw a vertical cross-section instead of a front view, to avoid a confusion of dotted lines.

54. As the shaft coupling is cylindrical in many of its parts, the easiest way to start a sketch of it is to draw the horizontal center line *ab*, Fig. 35, representing the center line of the shafts. On each side of it are drawn lines parallel to it to

represent the shafts, the outside of the hubs, and the inside and outside faces of the flanges on the halves of the coupling. All these lines should be drawn lightly, and at distances from *ab* corresponding to the diameters of the several parts, to the scale chosen for the sketch. The two parts are practically alike, and so the vertical center line *cd* is drawn, at right angles to *ab*. On each side of *cd* are laid off the distances that represent the width of the flanges, thickness of the coupling, and length of hub, and vertical lines at these distances then complete the general outline of the piece.

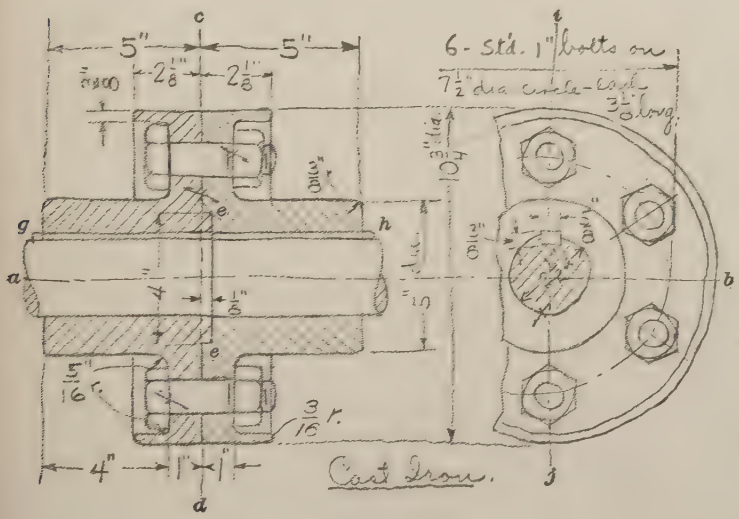


Fig. 35

55. The bolts that join the halves of the coupling are on a bolt circle $7\frac{1}{2}$ inches in diameter; so, in the sectional view, Fig. 35, the center lines of opposite bolts are drawn $3\frac{3}{4}$ inches on each side of the center line *ab*. On each of these short center lines is drawn the outline of a standard 1-inch bolt with hexagonal head and nut. As each half of the coupling has a thickness of 1 inch, measured at the bolt holes, the bolt is 2 inches long between head and nut, and so the total length of bolt should be about $3\frac{1}{8}$ inches. At the center, the line *ee* is drawn $\frac{1}{8}$ inch from *cd* and parallel to it, and 4 inches long, to represent the

recess in the right half and the projection on the left half. This construction is used to insure alinement of the shafts when the coupling is put together. The key in each half of the coupling is bedded half in the shaft and half in the coupling; as the depth of the key is $\frac{3}{8}$ inch, the line *gh* that represents the upper edges of the keys is drawn $\frac{3}{16}$ inch above the horizontal line that represents the top of the shafts.

56. After the outlines of the various parts have been drawn in light lines, they should be traced distinctly by heavy lines, as shown in the sectional view, Fig. 35; and then the cross-section lines should be filled in. It should be observed that the direction of the cross-section lines is different in the halves of the coupling. One half has section lines sloping downwards from right to left and the other has section lines sloping downwards from left to right. This is the usual practice in making drawings. Whenever the sections of two parts meet, the section lines should be drawn in opposite directions to indicate that the parts are separate pieces. If the section lines all ran in one direction, it would be difficult to distinguish between one piece and the other. When the sectional view has been completed, the end view may be drawn. It consists largely of circles constructed on the center lines *ab* and *ij* in the usual way. It also shows the dimensions of the key. Projection lines drawn from the sectional view parallel to *ab* will assist greatly in drawing the end view.

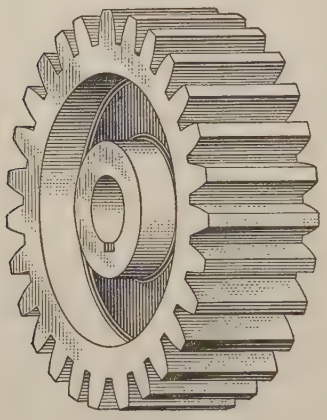


FIG. 36

57. Spur Gear.—The sketcher of machine parts will frequently be called on to make sketches of gear wheels, an example of which is shown in Fig. 36. The making of the sketch is not difficult; but before the sketch can be made, it is necessary to find the various dimensions of the gear, particularly those

relating to the pitch of the teeth. The first step is to find the outside diameter of the gear, or the diameter over the ends of the teeth. If the number of teeth in the gear is even, this may be done by use of an outside calipers. If the number of teeth is odd, the outside circumference can be found by wrapping a measuring tape around the wheel. If that circumference is then divided by 3.1416, the quotient will be the outside dia-

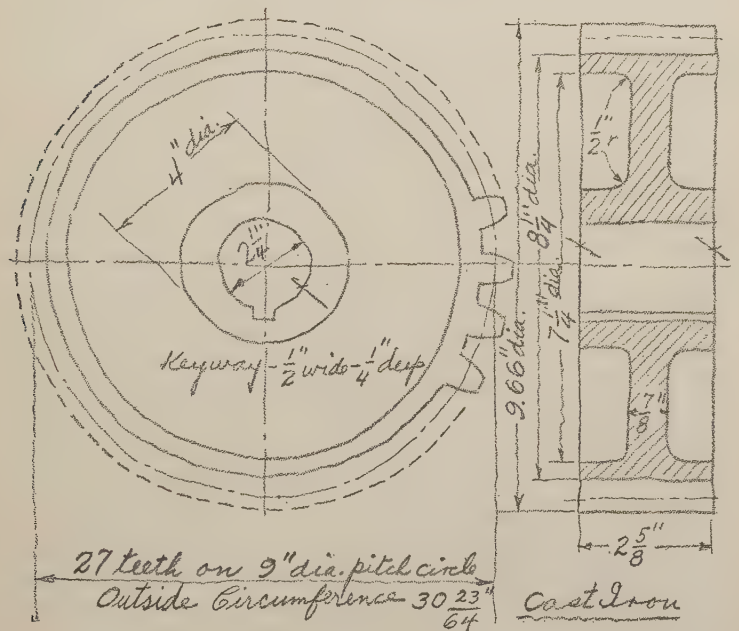


Fig. 37

meter of the wheel. When the outside diameter and the number of the teeth are known, the pitch can be found by calculation; but it is not necessary for the sketcher to make the calculation. All that is required of him is that he mark on the sketch the number of teeth and the outside diameter. If the outside diameter is found from the circumference instead of by direct measurement, it would be well to mark the outside circumference on the sketch, also, so that the calculation of the diameter may be checked.

58. Suppose that the gear in Fig. 36 has 27 teeth and that the outside circumference is found by measurement to be $30\frac{23}{64}$ inches. Then the outside diameter is $30\frac{23}{64} \div 3.1416 = 9.666$ or $9\frac{2}{3}$ inches. The diametral pitch, or number of teeth per inch of pitch diameter, is found by adding 2 to the number of teeth and dividing the sum by the outside diameter; hence, the dia-

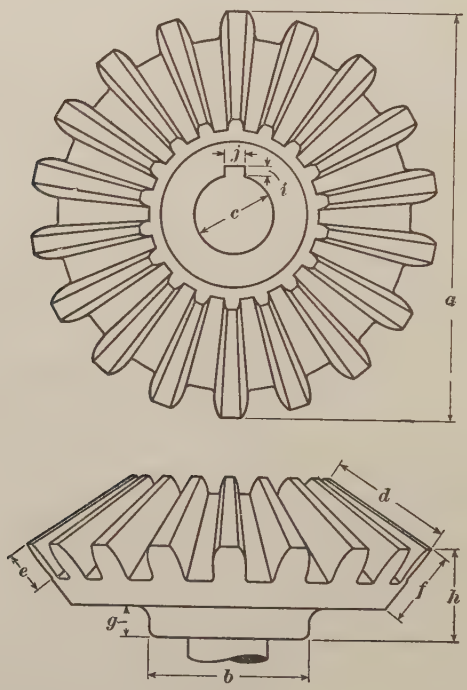


Fig. 38

metral pitch is $(27+2) \div 9\frac{2}{3} = 3$. The pitch diameter of the gear is equal to the number of teeth divided by the diametral pitch, and is $27 \div 3 = 9$ inches. The sketch of the gear, consisting of a side view and a vertical section, is shown in Fig. 37. It is drawn in the same manner as the flywheel sketched in Fig. 27. No attempt is made to draw the teeth, as to do so would serve no good purpose and would be a waste of time. It is sufficient to give the dimensions of the piece, the number of teeth, and

the pitch. From these data can be found the correct size of cutter to cut 27 teeth of the required shape and size.

59. Bevel Gear.—Suppose that a sketch is to be made to show the data required for making a bevel gear such as that illustrated in Fig. 38. In a case of this kind, the dimensions are the most important part of the sketch; and since all plain bevel gears are very much alike in general appearance, the

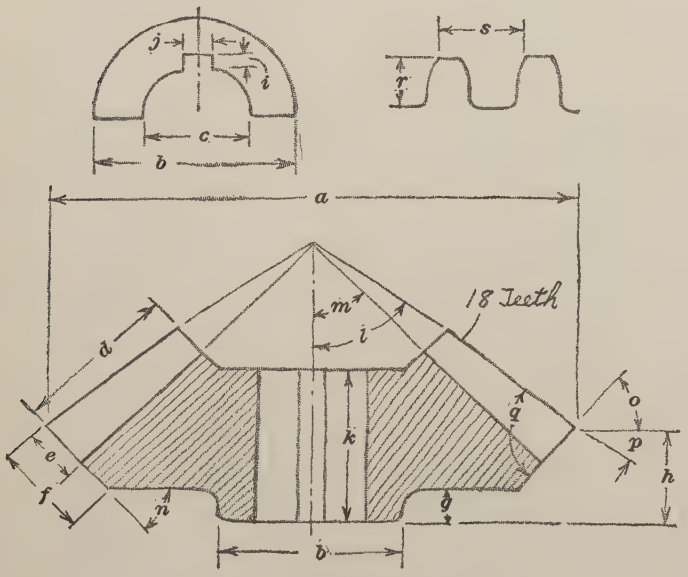


FIG. 39

simplest and easiest method is to draw a sketch showing a sectional view of a bevel gear and then mark on it the dimensions required for making such a gear. The sectional view is shown in Fig. 39. It shows a bevel gear cut in two diametrically in the plane of the axis of the hub. The various angles and dimensions that should be found are indicated. To determine these measurements, a steel scale and a bevel protractor or angle gauge are required. The several linear measurements to be taken, except the length of the bore of the hub, are shown in Fig. 38. They are the outside diameter *a* of the gear blank,

the hub diameter *b*, the bore *c*, the face *d*, the total depth of tooth *e*, the length *f* of the edge, the height *g* of the hub, the backing *h*, and the dimensions *i* and *j* of the keyway. In addition, the length of the bore in the hub should be found. All these dimensions should be marked on the sketch, Fig. 39, as indicated by the letters *a* to *k*.

60. In order to lay out a bevel gear, certain angles must be determined, as shown in Fig. 39. The blank angle *l* may be found by setting the stock of the protractor on the outer or top surface of the tooth in Fig. 38 and the blade against the inner face of the bore in the hub; or, it may be necessary to hold a steel rule against the face of the bore and set the protractor against it. The cutting angle *m*, Fig. 39, is found in a similar manner, but the blade of the protractor must rest along the bottom of the space between two teeth. The edge angle *n* may be measured directly by applying the protractor to the back and edge of the gear in Fig. 38. The angles *o* and *p*, Fig. 39, ought to be known, and are not hard to find. The angle *o* is exactly equal to the angle *n*. If the angle *q* is measured on the actual gear, then the angle *p* is equal to the angle *q* minus the angle *o*.

61. In addition to the dimensioned sectional view, Fig. 39, it is well to count the number of teeth in the gear and to mark this on the sketch, as shown. It is also wise to obtain the outline of the large ends of two adjacent teeth, as shown in the auxiliary view. This may be done by pressing the sheet of sketching paper against the edge of the gear until the impression of two adjacent teeth is obtained, after which the lines of the impression may be traced with the pencil. The height *r* in this view is the same as the dimension *e* in the main view, and the distance *s* is the pitch of the teeth.

If the mating gear to that shown in Fig. 38 is available, the numbers of teeth in both gears should be counted and marked on the sketch. The outside diameter *a*, over the tips of the teeth, can be found by calipering, if the number of teeth in the gear is even; and if there is an odd number of teeth, it may

be found by measuring the circumference of the gear at the tips of the teeth, using a steel tape, and dividing the circumference by 3.1416.

PIECES REQUIRING MORE THAN TWO VIEWS

62. Bracket.—A machine part may be of such form that at least three views will be required to show its shape and dimensions clearly. The cast-iron bracket in Fig. 40 is an example. The base *a* is $4\frac{1}{2}$ inches long, $1\frac{1}{4}$ inches wide, and $\frac{1}{2}$ inch thick, and contains two $\frac{1}{2}$-inch drilled holes *b* the centers of which are $3\frac{1}{4}$ inches apart. The uprights *c* are $\frac{7}{16}$ inch thick and $3\frac{3}{8}$ inches high, measured from the upper face of the base, and are $1\frac{1}{8}$ inches apart, being at equal distances from the center of the base. At their upper ends are bosses *d* $\frac{1}{16}$ inch high and $1\frac{1}{4}$ inches in diameter, through which are drilled $\frac{3}{4}$-inch holes *e* in line with each other. The centers of these holes are $3\frac{1}{4}$ inches above the lower face of the base. An oil hole *f* $\frac{1}{8}$ inch in diameter is drilled in the center of the top of each upright.

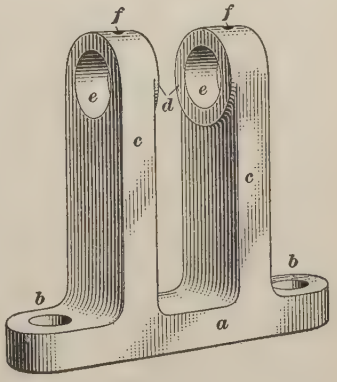


FIG. 40

63. The sketch of the bracket illustrated in Fig. 40 consists of three views and is shown in Fig. 41. The front view (*a*) is the first to be drawn. A horizontal base line *ab* is lightly drawn and a part of it is marked off to represent the base of the bracket, $4\frac{1}{2}$ inches long. On this line is constructed a rectangle $4\frac{1}{2}$ inches by $\frac{1}{2}$ inch, representing the front view of the base. The vertical center line *cd* is drawn through the center of the rectangle, and on each side of it, at a distance of $\frac{9}{16}$ inch, is drawn the vertical line representing the inner face of the upright. Outside each of these lines at a distance of $\frac{7}{16}$ inch is drawn a vertical line denoting the outer face of the upright. These four vertical lines are joined to the upper face of the base by fillets of $\frac{1}{4}$-inch radius. The tops of the uprights are

short horizontal lines $3\frac{7}{8}$ inches above the base line *ab*. The bosses are made to project $\frac{1}{16}$ inch inside each upright and are $1\frac{1}{4}$ inches in diameter. The side view (*b*) is easily constructed by drawing the vertical center line *ef* and then drawing horizontal projection lines from view (*a*), as shown. The third view (*c*), a top view, is necessary to show the shape of the base

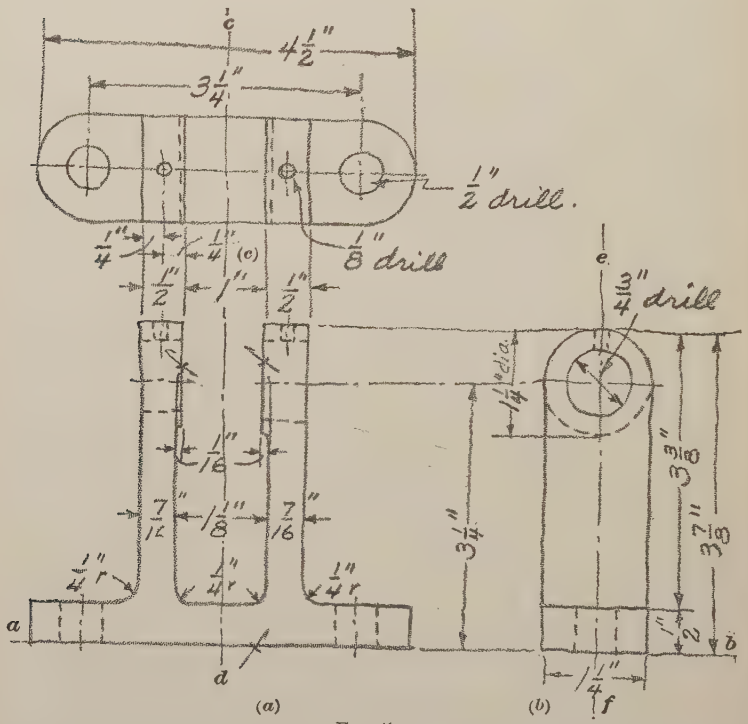


FIG. 41

of the bracket. Views (*a*) and (*b*) indicate the total length and width of the base but they do not show whether the ends are square or rounded. View (*c*) at once gives this information, as it shows the ends to be semicircles of $\frac{5}{8}$-inch radius, having the same centers as the holes in the base.

64. Practice Sketch II.—It is suggested that at this point the student submit another practice sketch, using the bearing

bracket in Fig. 42 as an example. The dimensions of the various parts are given in the illustration. The only parts of the casting that are to be finished are the inside faces of the uprights, as at *a*, the upper flat faces *b*, the semicylindrical surfaces *c*, and the bottom face of the casting. The drilled holes are at the centers of the faces *b*. The sketch to be made should show a side view, a top view, and an end view, and should contain all the necessary dimensions, as well as the finish marks. It is suggested that the sketch be drawn about half the full size. The directions as to the method of submitting this sketch are the same as those given in Art. 44, except that the sheet should be marked "Practice Sketch II."

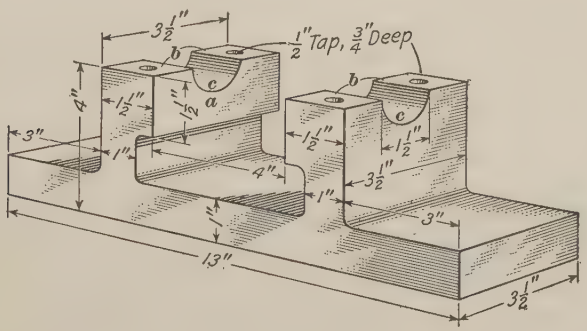


FIG. 42

65. Foreshortening.—In each of the sketches drawn thus far, the direction in which the piece is viewed is at right angles to some face of the piece. It is only when a surface is thus viewed that its dimensions appear in their true lengths. If the face of a piece is at an angle to the line of vision it will appear foreshortened; that is, some of the dimensions will appear shorter than they really are. The block shown in Fig. 43 will illustrate the point. It is a cylinder from which has been cut the piece indicated by the dotted lines, and the cut is at a slight angle to the axis of the cylinder. As a result, the area *abcd* is wider at the top *ab* than at the bottom *cd*.

Suppose that the block is sketched in two views, as in Fig. 44 (*a*) and (*b*). In looking at the block squarely from the front, the edges *ad* and *bc*, Fig. 43, are directly in line, and so they

appear in the front view (*a*) as a straight line *ad*. If the block is viewed from a point directly above the central hole *e*, it will appear as in the top view (*b*). As the edge *cd* is farther from the axis of the cylinder than is *ab*, both these edges can be seen and hence both will appear in the top view. The edges *ad* and *bc* also can be seen, but they will appear as short arcs *ad* and *bc* in the top view; in other words, they will be greatly foreshortened. Thus, the length *ad* in the top view does not rep-

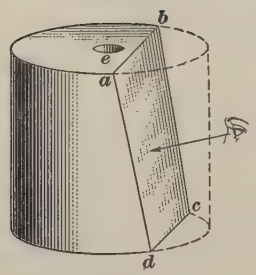


Fig. 43

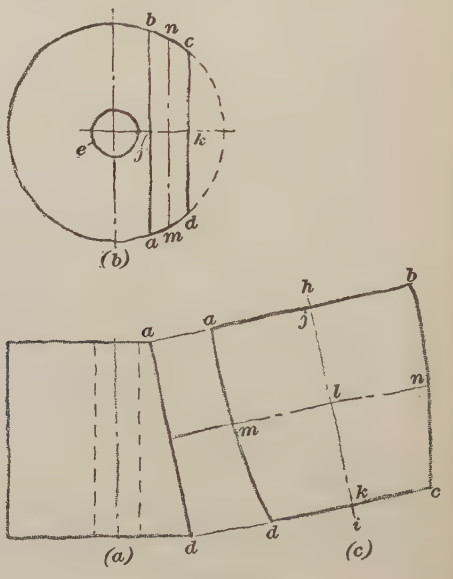


Fig. 44

resent the true length of that edge on the actual block, nor does *bc* represents the true length of the edge *bc* on the block. The reason is that the sides *ad* and *bc* of the surface *abcd* are not at right angles to the line of vision. On the other hand, the edges *ab* and *cd* are at right angles to the line of vision, and so they appear in their true lengths in the top view.

66. The only way in which all four sides of the face *abcd*, Fig. 43, would appear in their true lengths would be to make a view of *abcd* as if seen in the direction of the arrow.

or at right angles to that surface. Viewing the surface at right angles avoids the effect of foreshortening. Such a view is shown in Fig. 44 (*c*). Lines *ab* and *dc* are drawn at right angles to *ad*, view (*a*), and then the center line *hi*, view (*c*), is drawn at right angles to *ab* and *dc*. On each side of *hi* the distances *ja*, *jb*, *kc*, and *kd* are laid off equal to *ja*, *jb*, *kc*, and *kd* in the top view (*b*). A line is drawn through *l*, view (*c*), the middle point of *jk*, and *lm* and *ln* are laid off equal to half of *mn*, view (*b*), this line *mn* being drawn midway between *ab* and *cd* and parallel to them. Then, in view (*c*), the lines *amd* and *bnc* are drawn. These are not straight lines, but are curved, being parts of the outline of an ellipse; for, when a cylinder is cut at an angle to its axis, the edges of the cut at the outer surface of the cylinder are parts of an ellipse. A view of an oblique surface, such as that shown in view (*c*), is called an *auxiliary view.*

MEASUREMENTS

INTRODUCTION

67. Rule for Recording Measurements.—When the necessary views have been drawn to show clearly the form of the piece, the sketch is completed by writing the dimensions on it. These dimensions are obtained by measuring the piece that has been sketched. To avoid mistakes, the following rule should be adhered to strictly: *As soon as a measurement has been taken, write it on the sketch; do not attempt to take several measurements before placing any of them on the sketch.* Failure to follow this simple rule will be certain to cause trouble.

68. Marking Measurements on Sketch.—Ordinarily it is sufficient to write a given measurement only once on a sketch. If the sketch consists of but one view, each dimension has but one place to be recorded; but if there are two or three views, it may happen that a certain dimension can be marked in any one of the views. In the latter case, it should be placed on one view only. For example, take the case of the gland shown in Fig. 22. The diameter of the cylindrical part and the diameter of the central hole are both placed on view (*a*), at the left. The circles *n* and *z*, view (*b*), represent these same parts; but it

would be unnecessary, and only a waste of time, to write the diameters of these circles in that view.

69. Accuracy of Measurements.—The accuracy with which measurements must be made depends on the nature and purpose of the piece that is sketched. A casting, for example, does not need to be measured with the same degree of accuracy as a finished bolt; and the teeth of gear wheels or the diameters of pieces that are assembled by forced or shrink fits must be measured more accurately than an ordinary bolt. In other words, some dimensions may be approximate, whereas others must be exact. In the case of the bracket shown in Fig. 40, for example, the only finished surfaces are the inside faces of the bosses and the bottom face of the base; consequently, the distance between the bosses should be measured accurately, as well as the height of the center line of the holes above the bottom face of the base. The distance between the centers of the $\frac{1}{2}$-inch holes in the base should also be accurately determined, because these holes must match the bolts by which the bracket is held. But such dimensions as the thickness of the base and the width of the uprights are less important and may be measured to the nearest sixteenth of an inch.

MEASURING INSTRUMENTS

70. Two-Foot Rule.—The instruments used for measuring linear dimensions are of various kinds, depending on the shape of the piece and the accuracy with which the dimensions must be found. If great accuracy is not required, the ordinary two-foot folding rule shown in Fig. 45 may be used, (*a*) being a front view and (*b*) a rear view. It is made up of four sections, hinged together, to allow it to be folded for convenience in carrying. The rule is usually made of boxwood, with brass joints and edges. It is divided into inches and fractions of an inch. Divisions smaller than $\frac{1}{16}$ inch are rarely marked on them, so that the smallest fraction that can be directly measured is $\frac{1}{16}$ inch, but with a little practice it is possible to locate the middle and quarter points between the sixteenth-inch marks with a fair degree of accuracy, thus making it possible to measure distances as small as $\frac{1}{32}$ inch and $\frac{1}{64}$ inch.

71. Steel Rules and Tapes.—Where greater accuracy of measurement is required, use is made of steel rules. The two kinds used in sketching are each 12 inches long, with gradua-

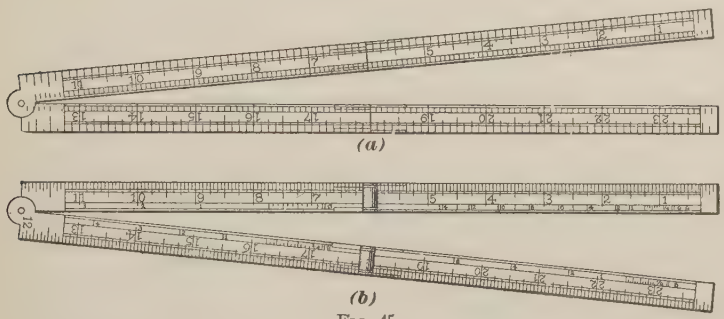


FIG. 45

tions on all four edges; but on one rule the inches on the four edges are divided into 8, 16, 32, and 64 parts, respectively, whereas on the other they are divided into 10, 20, 50, and 100 parts. Thus there is a wide choice of graduations for measurements demanding different degrees of accuracy. In measuring distances greater than a few feet, steel tapes are very convenient.

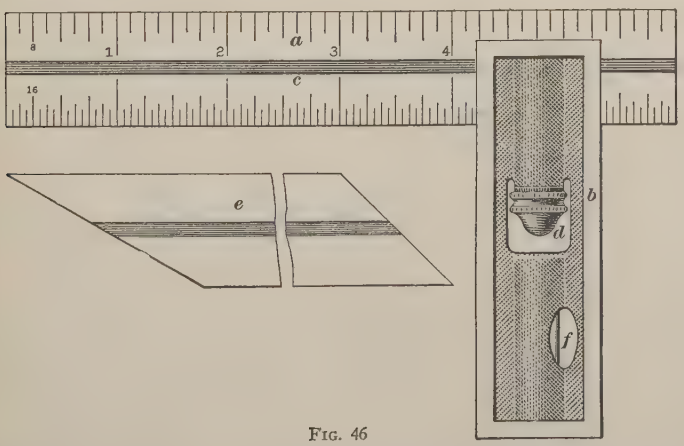


FIG. 46

They are flexible bands of steel from 2 to 100 feet long; but as the graduations are not very small, they are suitable only for taking approximate dimensions.

72. **Adjustable Square.**—An instrument that comes into frequent use is the square. It is best to have one with an

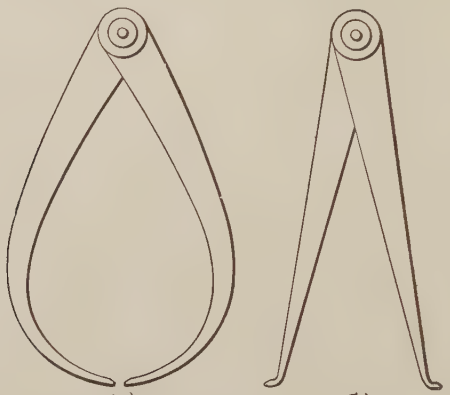


FIG. 47

adjustable blade, called an adjustable square, such as is shown in Fig. 46. The blade *a* is held in the stock *b* by a hook clamp that enters the groove *c* in the blade and is tightened by the

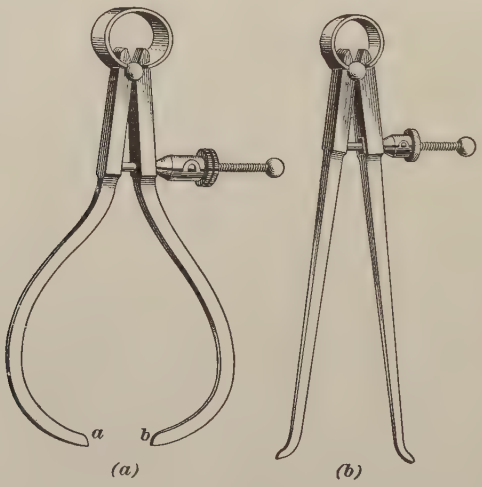


FIG. 48

nut *d*. The stock can be set at any point throughout the length of the blade, and also, of course, flush with the end of it, thus

serving also as a *solid square*. A special bevel blade *e* for testing angles of 45° and 30° is generally furnished with this square. The stock is usually provided with a level at *f* that may be used in testing either a vertical or a horizontal surface. It should be borne in mind that a square is perfect only when the blade and stock are exactly at right angles to each other, and that a fall or any careless use is liable to impair its accuracy and its usefulness.

73. Calipers.—Calipers are of numerous shapes and sizes. They are used to measure either diameters or widths and lengths, from a small fraction of an inch to several feet. The

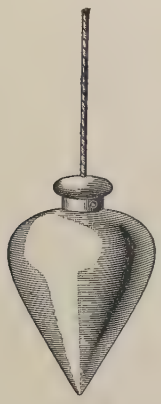


FIG. 49

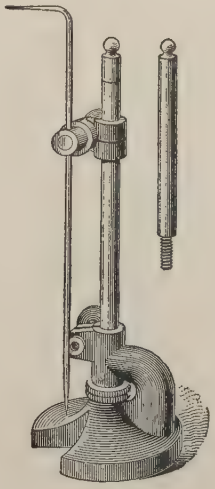


FIG. 50

simplest forms of calipers are shown in Fig. 47, where view (*a*) illustrates *outside calipers*, used for taking outside measurements, of shafts, wheels, and similar articles, and view (*b*) shows a companion tool, the *inside calipers*, which, as the name implies, is used to measure the diameter of holes, or the distance between two objects. Another class of calipers is provided with an adjusting screw, as shown in Fig. 48 (*a*) and (*b*). Calipers are often used to measure the outside diameter of screws, and when so used are made as in (*a*), except that the contact sur-

faces *a* and *b* are made wide enough to reach across two or more threads. Similar calipers are used to measure the bottom of screw threads, in which case the points are beveled and thin, like a knife blade.

74. Plumb-Bob.—The plumb-bob is often very convenient to have among the tools used in sketching, although any small piece of metal, as a nut, a penknife, or other small, heavy object tied to a thread does equally well in most instances, since it does not often happen in sketching that a plumb-line must be established over a certain point; in this latter case, a regular plumb-bob having a sharp point would be required, as shown in Fig. 49.

75. Surface Gauge.—A surface gauge consists of a flat base to which is attached a vertical standard that carries an adjustable scriber. A simple form of this instrument is shown in Fig. 50. Its use in sketching will be more fully treated in the following pages.

TAKING MEASUREMENTS

76. Straight Linear Measurements.—Perhaps the simplest of all measurements is the distance between two points on a flat surface, as, for example, the distance between opposite edges of such a surface. Such a measurement is the length of the side of the washer shown in Fig. 13, or the thickness of the washer. A measurement that is equally simple is the thickness of the head of the stop pin shown in Fig. 15, or the length of the shank of the pin. Such measurements as the foregoing are made with the rule.

77. Distance Between Parallel Faces.—Frequently it is necessary to measure the distance between parallel faces of a piece, as, for example, the overall length of the gland in Fig. 22, indicated by the dimension $1\frac{3}{8}$ inches. One way of doing this is illustrated in Fig. 51 (*a*). The gland is stood on end on a flat surface and the stock of an adjustable square is laid across the top of the flange. The blade is then moved down until it just touches the supporting surface and the total height is read

from the blade. The same method may be used if a piece has rounded corners, as, for example, the safety collar shown in (*b*).

It is not always convenient or possible to measure distances between parallel faces by means of the adjustable square in the manner just described. In such cases, the outside calipers are used; thus, while the distance across flats of the hexagonal head of the bolt, Fig. 17, may be measured with the square, it is more convenient to use the calipers, while the thickness of the webs *d* of the pump valve seat in Fig. 31 must be measured with the

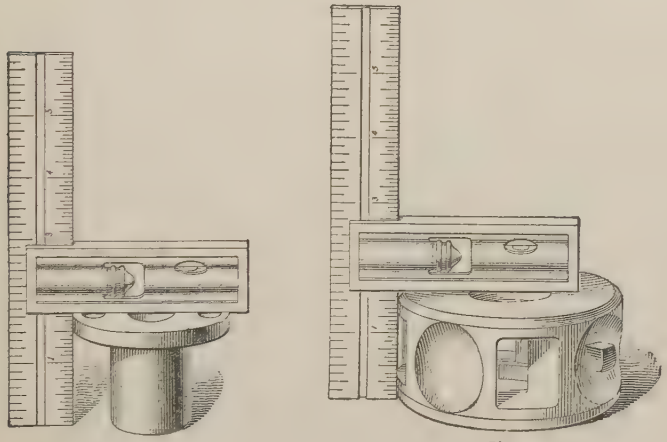


FIG. 51

outside calipers, because a rule cannot be laid across the top surface of any web.

78. Outside Diameters.—Ordinarily, outside diameters of pieces are measured by the use of the outside calipers. The application of this instrument is shown in Fig. 52. First, the points of the calipers are separated so that they pass over the shank of the piece without touching it. Then, by gently tapping the outside edge of one of the legs against some convenient object, the calipers may be gradually closed until the points just touch the shank, as shown. There should be no play, nor should the points pinch too hard. It requires a little practice to get the proper touch by tapping the calipers. The process is

easier with the form of calipers shown in Fig. 48, as the adjusting screw may be turned a little at a time until the points of the calipers just pass over the shank. After the calipers are set

FIG. 52

to the diameter of the piece, the measurement is found by applying the calipers to a steel rule in the manner shown in Fig. 53.

79. It often happens that very large diameters are to be measured, for which the calipers available are too small, as in the case of pulleys, wheels, and similar objects. In such cases

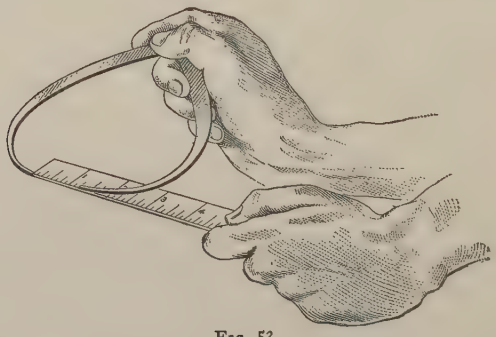


FIG. 53

it may be possible to measure accurately enough across the side of the object, as a pulley, for instance, with a long rule or a stick; but just as often this cannot be done because other parts

are in the way, as, for instance, when a pulley is keyed to a shaft, perhaps near to a hanger. In most cases the steel tape furnishes an excellent means for finding the diameter. The tape is wrapped around the wheel or pulley and the outside circumference is measured; then this measurement is divided by 3.1416, the quotient being the diameter.

80. In the absence of a tape, the diameter of a wheel or pulley can be obtained by measuring from a point on the circumference of the shaft to a point on the rim of the wheel or pulley and adding twice this amount to the diameter of the shaft as measured with outside calipers. Care must be taken to get the correct measurement by moving the rule slightly in an arc

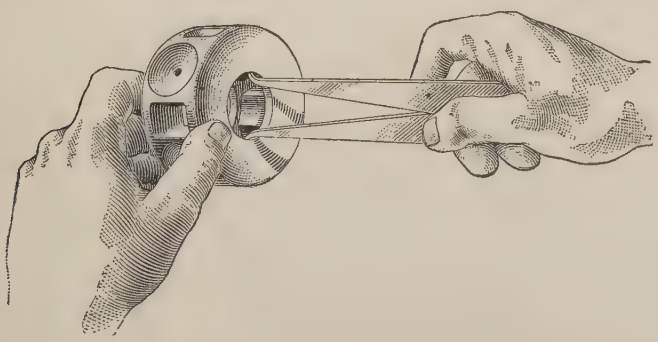


FIG. 54

and watching the greatest reading where the outer edge of the rim comes opposite the rule. This will serve as a check to determine when the rule is held radially.

81. **Inside Dimensions.**—To measure inside dimensions, such as the diameters of holes, for instance, the inside calipers are used, as in Fig. 54. The procedure is the same as with outside calipers, but care must be taken in tapping the instrument not to strike on the points, as these will be easily damaged thereby. After the instrument is adjusted, the distance between the points is measured with the rule, as shown in Fig. 55, by holding the end of the rule against some smooth, flat surface, whenever practicable, and then letting the point of the caliper leg press against this surface.

82. **Distance Between Centers.**—The distance between two centers, as of two holes or of two shafts, or the distance between a surface and the center of a hole, cannot ordinarily be measured

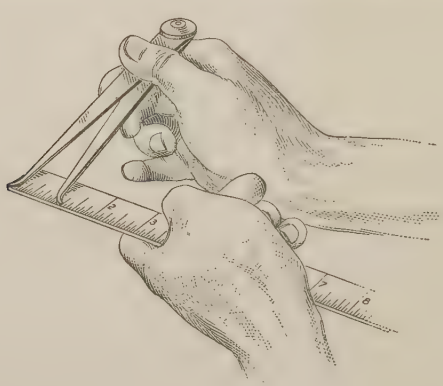


FIG. 55

directly with instruments. Oftentimes much ingenuity is required to obtain the desired dimensions. A case that frequently occurs is the finding of the distance between the center

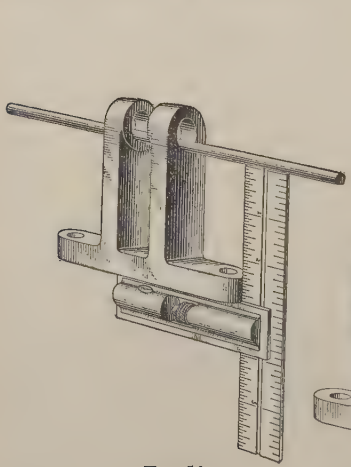


FIG. 56

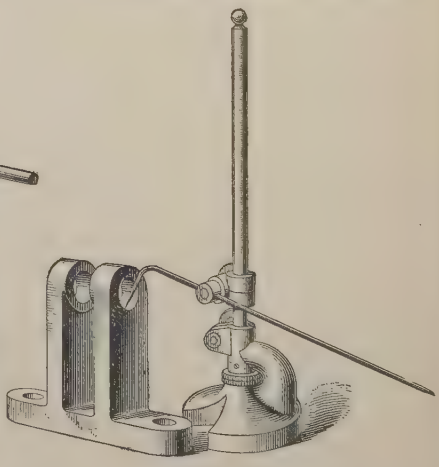


FIG. 57

lines of two holes, as, for instance, the holes in the flange of the gland in Fig. 21. This dimension can be found by measuring, with the outside calipers, the distance between the inside

edges of the two holes, and adding to that measurement half the diameter of each hole. The distance between the inside edges of the holes, as found by the calipers, is $1\frac{11}{16}$ inches. The diameter of each hole, found by using inside calipers, is $\frac{9}{16}$ inch. Then, the distance from center to center of the holes is $1\frac{11}{16} + \frac{9}{32} + \frac{9}{32} = 2\frac{1}{4}$ inches.

83. Suppose that it is desired to find the distance between the bottom face of the bracket, Fig. 40, and the center line of the holes in the uprights. It may be obtained by measuring the distance from the bottom of the hole to the bottom of the base and adding to it half the diameter of the hole. The first dimension is, however, not directly measurable with a rule, but must be obtained by prolonging the bottom line of the hole by means of some convenient straight piece and using the square, as shown in Fig. 56. The straight piece should preferably be round in section, as its under edge will then more accurately represent the prolongation of the bottom line of the hole; however, a straightedge, if quite thin, may be used by exercising care.

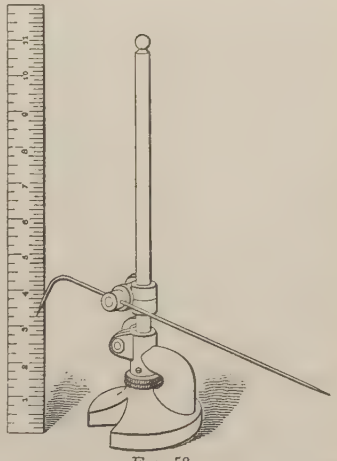


Fig. 58

84. At first thought, it might seem that an easier way to find the distance from the base of the bracket, Fig. 40, to the center line of the holes would be to measure the total height of the piece and deduct from it the thickness of the metal on top of the hole and half the diameter of the hole. But this would not give a reliable measurement, as the piece is not finished on top, whereas the bottom is, and as the dimension sought is an important one, it must be accurate. An easier way to get the measurement, however, is by the use of the surface gauge. The bracket and the surface gauge are set on a flat plate, as shown in Fig. 57, and the gauge is adjusted so that the point of the

scriber lightly touches the bottom of the hole. The gauge is then removed and the distance from the plate to the point of the scriber is measured by a steel rule, as shown in Fig. 58.

85. Another example of finding the distance of a center from a plane surface is shown in Fig. 59. The adjustable square is used to find the distance from the top of the frame of the machine, which is finished, to the top of the collar below. To this is added half the diameter of the collar, ascertained by means of the outside calipers.

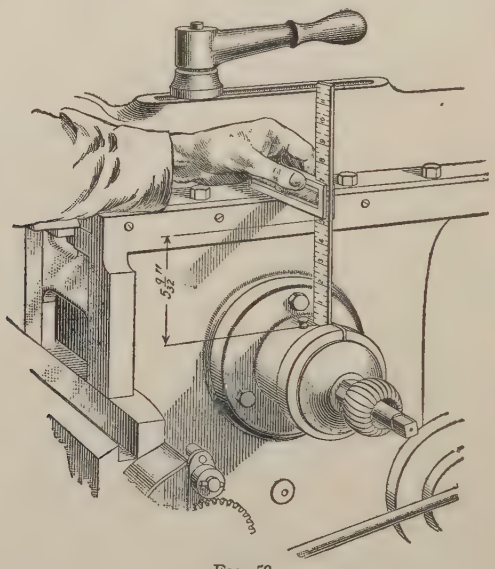


FIG. 59

A further example is given in Fig. 60. It was required to measure the horizontal distance of the center of the shaft from the vertical finished front of the machine. The square could not be used in the same manner as in Fig. 59, as the sliding carriage, already in its lowest position, was in the way. The dimension had thus to be transferred higher, as it were. The plumb-bob was conveniently suspended, so that the plumb-line just touched the left side of the disk. Next, the distance between this line and the front of the machine was measured

and half the diameter of the disk added thereto. Before this method could be employed, however, it had to be ascertained

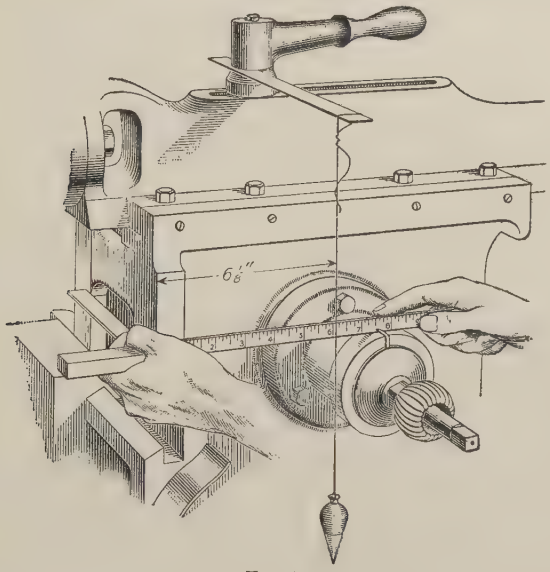


FIG 60

whether the machine so stood on the floor that the front surfaces of the frame were vertical. This was found not to be the case, and it had to be wedged up on one side to make it so.

86. Distance Between Centers of Gear-Wheels.—The distance between centers of two gear-wheels in mesh must be measured with particular accuracy, as it furnishes a means by which to ascertain accurately the pitch of the gears. If the shafts are accessible, either in front of or behind the gears, the distance between centers is easily established by measuring the distance between the shafts by means of inside calipers if the distance is short; or, if the distance is greater, it

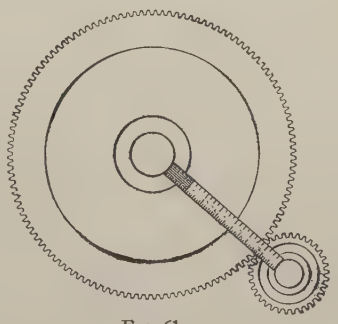


FIG. 61

may be done by means of two steel rules slid one on the other, as in Fig. 61, where the visible portion of the underlying rule is shown shaded. To this measurement the radii of the shafts are added.

87. If the shafts are flush with the wheels, so that the distance between centers cannot be measured in the foregoing manner, and if there are no hubs to make use of, the distance may

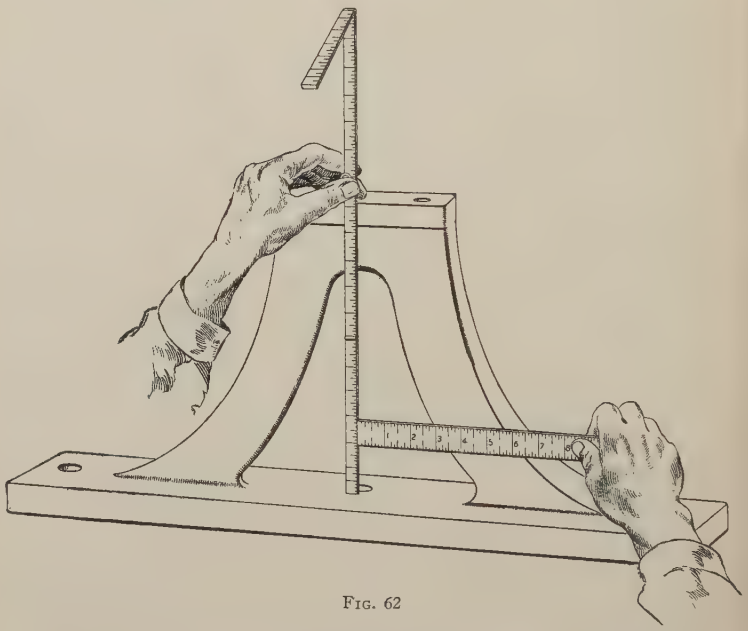


Fig. 62

be obtained by measuring across the wheels themselves and deducting their outside radii. This method will be absolutely exact, however, only if the number of teeth in each wheel is even, because, if the number is odd, the outside diameter cannot be measured accurately with the calipers; there is a tooth on one end of the diameter and a space on the opposite end, the measurement being between the point of the tooth on the one end of a diameter and the point of the tooth next to the space at the other end of the diameter. The difference between the dimen-

sions obtained in this way is, however, but very slight in ordinary cases.

88. After the distance between the centers of two gears has been found, the diametral pitch may be determined by taking the sum of the numbers of teeth in the two wheels and dividing it by twice the distance between centers. Sometimes the *circular pitch* is desired. This is the distance, measured along the pitch circle, from a point on one tooth to the corresponding point on the next tooth of the same wheel; it is equal to the circumference of the pitch circle divided by the number of teeth in the gear.

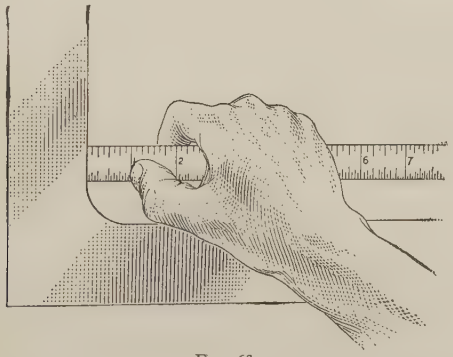


FIG. 63

By calculating both pitches, it is generally recognized by what system the gears are constructed. Thus, if the calculation yields, for instance, a whole number, or a whole number and a half, or a whole number and a quarter, for the diametral pitch, but an awkward decimal number for the circular pitch, it is fair to assume that the gears are cut to the diametral pitch indicated by that number. If the calculation yields an awkward decimal number for the diametral pitch, but a whole number, or a whole number and simple fraction for the circular pitch, it is fair to assume that the gears are cut to circular pitch.

89. **Curved Outlines and Fillets.**—When curved outlines occur in frames of machines, they sometimes give considerable trouble in sketching. Fortunately, the dimensions are in such cases seldom required to be exact, and the measurements can be

rounded off. The frame shown in Fig. 62 is an example. To obtain the curved outline of the legs of the stand, the two-foot rule is placed vertically to represent the center line, and hori-

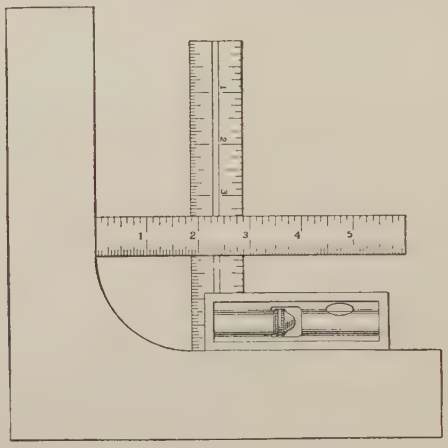


Fig. 64

zontal measurements are taken with another rule at various heights on the vertical rule. This method is of especial value where curves are not parts of circles.

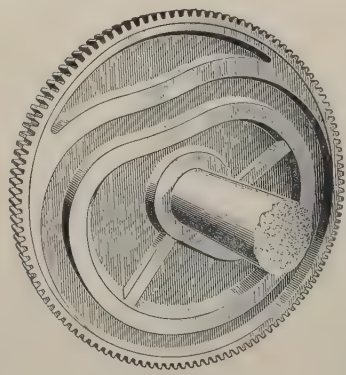


Fig. 65

90. Sharp corners are avoided in machine frames whenever possible, being rounded off by fillets. It is generally sufficient to measure the radii of such fillets approximately. Small ones may be judged entirely by the eye, by placing the rule against the surface of the object where one end of the curve begins and reading off the length to a point that appears to be just in line with the other end of the curve, as shown in Fig. 63. Large fillets are best measured by means of the rule and square, as shown in Fig. 64, by placing the rule against one surface of the object where the curve begins and the square on

the other surface, and sliding it against the rule until both indicate the same distance.

91. There are cases in which it is essential to get a curved outline exactly. In such cases it is best, if possible, to trace the outline by placing the object on the sketch pad and running the pencil point along the curves. Evidently this method cannot always be used, as, for instance, when the object is large or when the curve is so located on the object that it cannot be traced. The cam shown in Fig. 65 is an example. In such cases nothing short of a templet, made of stiff paper or even tin plate, will suffice. The sheet is placed over the curve and by pressure with the hand or rapping with a peen hammer the outline is transferred to the sheet.

PICTORIAL SKETCHING

ISOMETRIC DRAWING

92. Use of Pictorial Sketches.—Freehand sketches made by the methods outlined in the foregoing articles will give the necessary information as to the size and shape of the details sketched; but such sketches are usually given to persons who are familiar with the reading of working drawings. Oftentimes it is necessary to explain the construction or operation of a machine part to some one who does not understand how to interpret a sketch made on the plan of a working drawing. Such a person would probably get a clearer idea from a photograph of the part. A photograph shows an object as viewed from a single point, and the view thus obtained is called a perspective. It is possible to make a perspective drawing of a machine part, showing the same essential details as are given by a photograph. But such a picture, or pictorial sketch, requires a knowledge of perspective drawing and takes too much time; as a result, simpler sketches of somewhat similar character are used, such as isometric sketches and oblique sketches.

93. Isometric Axes.—An isometric sketch of any kind is based on three lines, or axes, that make equal angles of 120 degrees with one another. Usually, one of these axes is vertical and the other two are on opposite sides of it, as in Fig. 66 (*a*)

and (*b*); but, one of the axes may be horizontal, as in (*c*), if desired. Isometric sketches are especially useful for showing

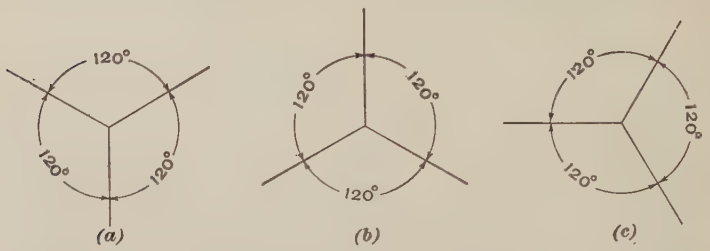


FIG. 66

in a single view the form and size of an object that is rectangular in its main outlines; but any machine part may be illustrated by an isometric sketch.

94. Angle Plate.—Suppose that an isometric sketch is to be made of the angle plate shown in perspective in Fig. 67, which is a casting consisting of two rectangular plates at right angles to each other, with a strengthening web at the middle. In drawing the isometric sketch, Fig. 68, the first step is to draw

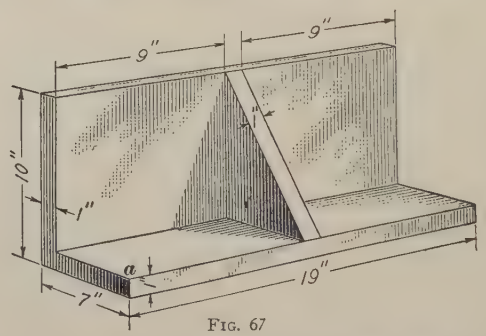


FIG. 67

the three axes *oa*, *ob*, and *oc* at equal angles with one another. Suppose that the corner *a*, Fig. 67, of the piece is assumed to be located at the point *o*, Fig. 68, where the axes meet. Then *od* is marked off downwards on *oa* equal to 1 inch, the thickness of the bottom plate. From *d*, lines are drawn parallel to *ob* and *oc*, and *de* is laid off 19 inches long, or the length of the plate, while *df* is made 7 inches, or the width of that plate.

95. From the point *c*, Fig. 68, a line is drawn parallel to *oa* until it meets *ob* at *g*; then *eg* is the right-hand corner of the front edge of the bottom plate. From *f*, the back corner of the left-hand end of the angle plate, *fh* is drawn parallel to *oa* and is made 10 inches long. Next, *hi* is drawn parallel to *oc* and 1 inch long, representing the thickness of the vertical plate, and from *i* the line *ij* is drawn parallel to *oa* to meet *oc* at *j*. From *h*, *i*, and *j* the lines *hk*, *il*, and *jm* are drawn parallel to *ob* and

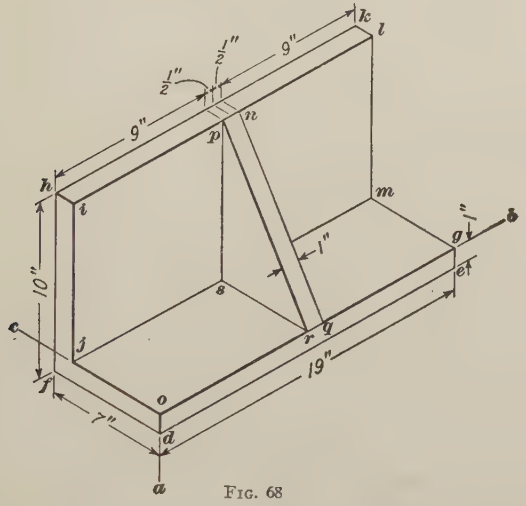


Fig. 68

each 19 inches long; then *gm*, *ml*, and *lk* are drawn, completing the outline of the two rectangular plates. The middle points of *og* and *il* are located, and the points *n*, *p*, *q*, and *r* are laid off ½ inch from the middle points, and *nq* and *pr* are drawn, representing the slanting face of the web. Finally, *ps* is drawn parallel to *oa* and *rs* parallel to *oc*.

96. Several points in the construction of the isometric sketch, Fig. 68, should be noted. All lines representing vertical edges of the angle plate are parallel to the axis *oa*, and all lines representing horizontal edges are parallel to either *ob* or *oc*. The diagonal edges of the strengthening web are neither horizontal nor vertical, and so, in the sketch, they are parallel to none of the axes. The sketch is constructed by laying off the actual

dimensions of the parts on lines parallel to the axes, and so it gives a very good idea of the relative sizes of the details. It should be observed that the dimension lines also are parallel to the axes and that the extension lines between which the dimension lines are drawn are obtained by producing the edge lines of the bracket. The dimension lines do not meet the extension lines at right angles, as in ordinary sketches.

97. Stop Pin.—An isometric sketch of a round or an irregular object is not so easy as a sketch of a rectangular object. Suppose that an isometric sketch of the stop pin shown in Figs. 15 and 16 is to be made. For the purposes of the sketch, it may be assumed that the shank of the pin is enclosed in a

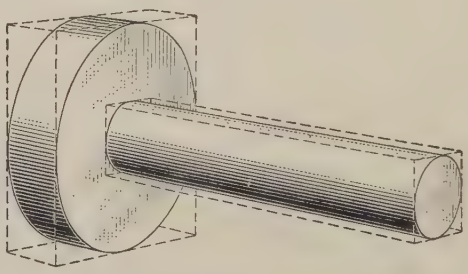


FIG. 69

square block whose length is the length of the shank and whose sides equal the diameter of the shank, as shown by the dotted lines in Fig. 69. Similarly, the head of the pin may be assumed to be enclosed in a square block as thick as the head and of the same width and length as the diameter of the head. If the rectangular blocks are then drawn isometrically, it is a simple matter to obtain the isometric outlines of the cylindrical parts.

98. The isometric sketch of the stop pin is shown in Fig. 70. First, the axes *oa*, *ob*, and *oc* are drawn, at equal angles of 120 degrees. The axis *ob* is assumed to represent the center line of the pin, and so the point *o* is the center of the visible end of the shank of the pin. This end is a circle $\frac{7}{16}$ inch in diameter, but it is enclosed by a square $\frac{7}{16}$ inch on each side, in Fig. 69. So the first step is to construct the isometric out-

line of that square. On the axis *oa*, Fig. 69, *od* is laid off on each side of *o* equal to half of $\frac{7}{16}$ inch, and *oe* is laid off on the axis *oc* to the same distance. Through *d* and *e* lines parallel to *oc* and *oa* are drawn, producing the parallelogram *fghi*, which is an isometric view of a square. The end of the pin, which is a circle, appears as an ellipse in an isometric sketch, and the ellipse is constructed inside the figure *fghi*.

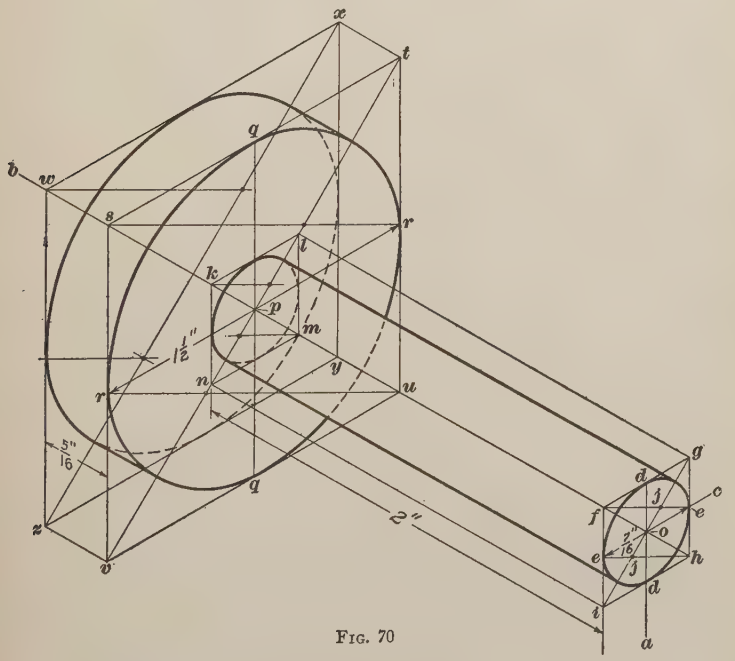


FIG. 70

99. The ellipse representing the end of the shank of the pin in Fig. 70 is constructed by drawing four circular arcs. The long arcs from *d* to *e* are drawn with *f* and *h* as centers, with radii equal to *fe* and *he*. The short arcs from *d* to *e*, forming the ends of the ellipse, are drawn with the points *j* as centers and radii equal to *jd* or *je*. The points *j* are found by drawing straight lines *fe* and *he* and noting where they cross the diagonal *gi*. From *o*, the distance *op* is laid off on *ob* equal to the length of the shank, or 2 inches. Around *p* as a center, the

parallelogram *klmn* is drawn, $\frac{7}{16}$ inch on a side, in the same way as *fghi*. Inside *klmn* another ellipse is constructed, by the same method as that just described, and these ellipses are then joined by straight lines that represent the sides of the shank of the pin.

100. The inner face of the head of the pin in Fig. 69 is enclosed by a square $1\frac{1}{2}$ inches on a side. So, in Fig. 70, the distances *pq* and *pr* are laid off from *p*, each $\frac{3}{4}$ inch long and parallel to *oa* and *oc*. Then, through *q* and *r*, lines are drawn parallel to *oa* and *oc*, giving the parallelogram *stuv*, inside which an ellipse is constructed by the method just described. This

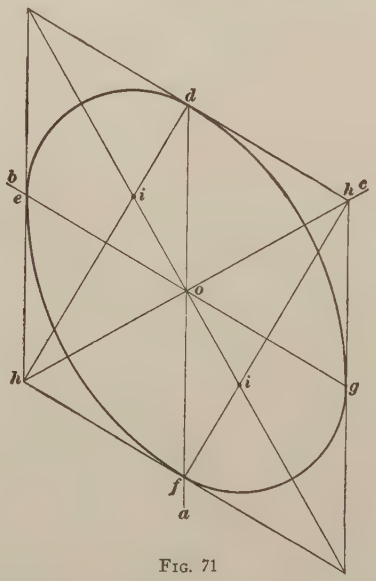


Fig. 71

ellipse *rqrq* then represents an isometric view of the inner face of the head of the pin. The head is $\frac{5}{16}$ inch thick; hence, the point *w* is located $\frac{5}{16}$ inch from *s* on the axis *ob*, and the parallelogram *wxyz* is drawn, $1\frac{1}{2}$ inches on a side. Inside it is constructed an ellipse, which is the outer face of the head of the pin. The two larger ellipses are joined by lines parallel to *ob*, and then those outlines which are not hidden behind solid parts are made heavier, as shown. Finally, the dimensions are placed on the sketch.

101. Isometric Drawing of Circles.—The procedure in connection with Fig. 70 explains how an isometric view of a circle is drawn when the circle is on a vertical face inclined to the right. If the face containing the circular outline, as of a hole, is inclined to the left, the isometric view may be drawn as indicated in Fig. 71. The center *o* of the circle is taken as the meeting point of the isometric axes *oa*, *ob*, and *oc*. On the axes *oa* and *ob*, prolonged, the distances *od*, *oe*, *of*, and *og* are laid off, each equal to half the diameter of the circle. Then lines are drawn through *d*, *e*, *f*, and *g* parallel to *oa* and *ob*, giving a diamond-shaped outline that is an isometric view of a

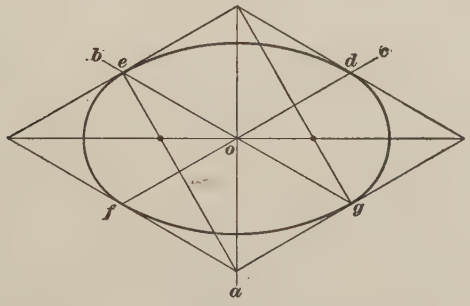


FIG. 72

square that will contain the circle. Inside this outline an ellipse is drawn. The flat sides *dg* and *ef* of the ellipse are drawn with the corners *h* as centers and *dh* and *fh* as radii. The ends of the ellipse are drawn with the points *i* as centers, these being at the points where *dh* and *fh* cut the diagonal of the figure.

102. If the circle is located on a horizontal surface, its isometric drawing is made as shown in Fig. 72. The axes *oa*, *ob*, and *oc* are drawn as before and the center of the circle is assumed to lie at *o*. The distances *od*, *oe*, *of*, and *og* are laid off equal to the radius of the circle and the diamond-shaped outline is drawn by lines parallel to *ob* and *oc*. Within this figure the ellipse is constructed by circular arcs in the same manner as that just described. Comparison of the ellipses in Figs. 70 to 72 shows that the long axis is horizontal in the case

of a horizontal face, slopes to the left in the case of a vertical face inclined to the left, and slopes to the right in the case of a vertical face inclined to the right.

OBLIQUE DRAWING

103. Advantages of Oblique Drawings.—In making an isometric sketch of a piece that has a cylindrical section or that contains a circular hole, it is necessary to draw an elliptical outline; and if there are many such details, the construction of numerous ellipses becomes tiresome. It is possible to avoid the drawing of so many ellipses by making use of oblique sketches. An oblique sketch is made on much the same principle as an isometric sketch; but it uses three axes, two of which are at right angles, the third making equal angles of 135 degrees with the other two, as shown in Fig. 73. If the piece to be sketched has a face that is circular, or that contains a circular hole, that particular face is drawn on the axes that are at right angles, and thus it can be shown in its true shape, without any distortion; in other words, circles appear as circles, and not as ellipses, and so they are more readily drawn.

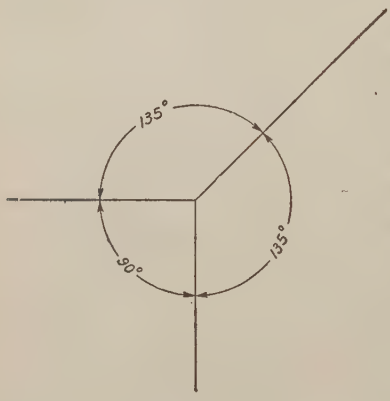


FIG. 73

104. Washer.—Suppose that the washer in Fig. 13 is to be shown by an oblique sketch. First, the axes are drawn, as indicated by *oa*, *ob*, and *oc*, Fig. 74. Now, assume the point *o* to represent the upper right-hand corner of the washer. On *oa* and *ob* lay off *od* and *oe*, each equal to the length of the side of the washer, or $2\frac{1}{2}$ inches, and complete the square *odfe*, which then represents the upper face of the washer in its true size and shape. On the axis *oc*, measure off *oq* equal to the thickness of the washer, or $\frac{3}{8}$ inch, and from *g* draw lines parallel to the axes *oa* and *ob*. Next, from *d* and *e* draw lines parallel

to the axes *oc*. They will cut the lines from *g* at *h* and *i*. Then *goei* is one edge of the washer and *godh* is another. At the

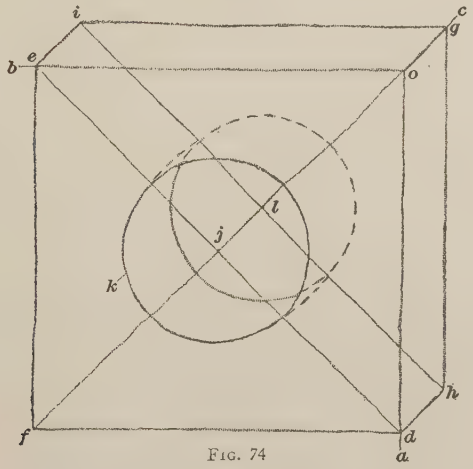


FIG. 74

center *j*, found by drawing the diagonals *of* and *ed*, draw a circle *k* with a radius of $\frac{5}{8}$ inch, which will be the top of the $1\frac{1}{4}$-inch hole in the washer. Part of the bottom edge of the

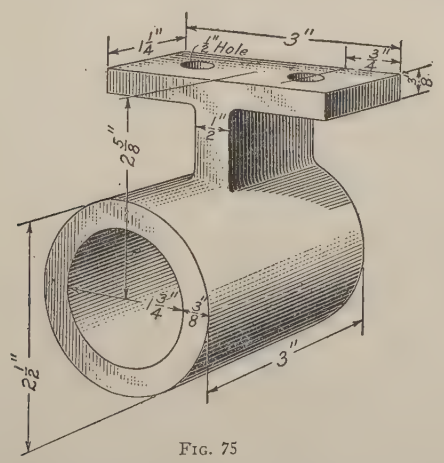


FIG. 75

hole can also be seen, and it is an arc of a circle of $\frac{5}{8}$-inch radius, too. But its center is at a point l $\frac{3}{8}$ inch from *j* and on

a line parallel to the axis *oc*; for, the center of this circle is at the center of the under surface of the washer, which is $\frac{3}{8}$ inch from the center *j* of the top surface.

105. Wall Bracket.—A wall bracket is shown in perspective in Fig. 75. The front end of the cylindrical part is rep-

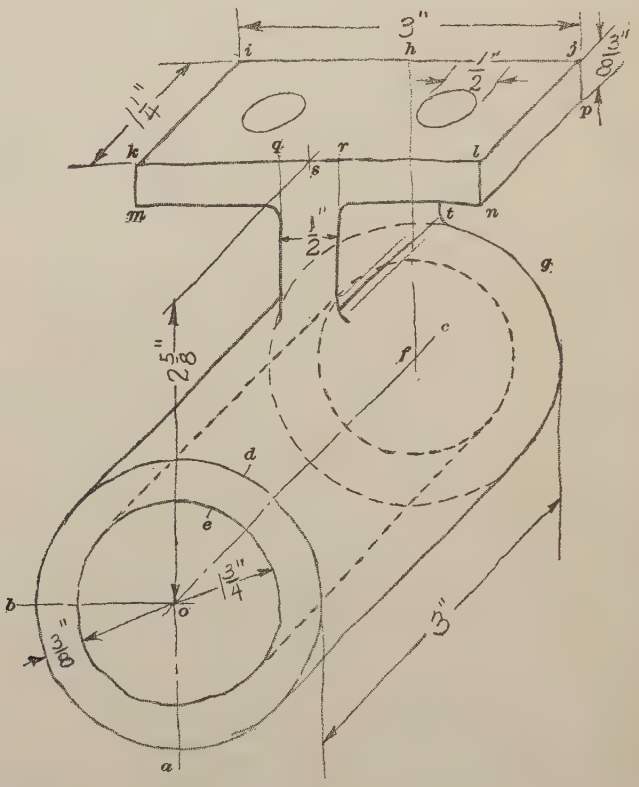


FIG. 76

resented by two circles that stand vertical, and the holes in the flat pad at the top are indicated by two horizontal circles. If an oblique drawing is made of the bracket, therefore, all of these circles will not appear in their true circular form. One set or the other will appear as ellipses. It is here assumed that the large circles representing the end of the cylindrical part are

shown in their true form. Then, as shown in Fig. 76, the axes *oa*, *ob*, and *oc* are drawn in the usual way, and on the axes *oa* and *ob*, with *o* as a center, the circles *d* and *e* are drawn, with diameters of $2\frac{1}{2}$ and $1\frac{3}{4}$ inches, respectively. The axis *oc* is taken to represent the center line of the cylindrical part of the bracket.

106. Along the axis *oc*, Fig. 76, the distance *of* is laid off equal to 3 inches, and the circle *g*, $2\frac{1}{2}$ inches in diameter, is drawn with *f* as a center, thus outlining the other end of the cylindrical body. Vertically above *f*, on a line parallel to *oa*,

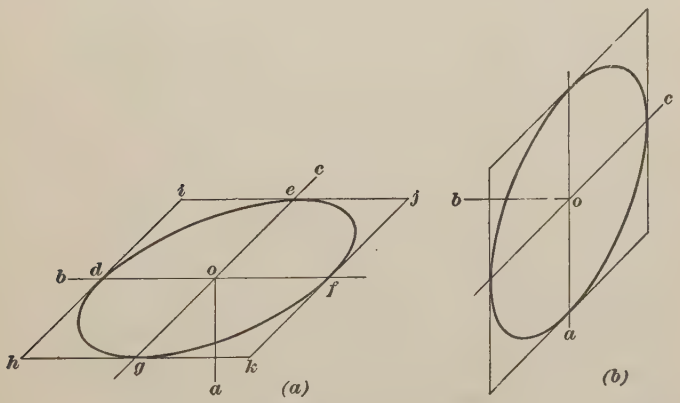


FIG. 77

the distance *fh* is laid off, $2\frac{5}{8}$ inches long, and the point *h* is then the middle point of the top rear edge of the rectangular pad. Through *h* the line *ij* is drawn parallel to *ob*, and *hi* and *hj* are each made $1\frac{1}{2}$ inches long. From *i* and *j* the lines *ik* and *jl* are drawn parallel to *oc*, and each $1\frac{1}{4}$ inches long. Then the line *kl* completes the outline of the top face of the pad. The visible lower edges *mn* and *np* are drawn $\frac{3}{8}$ inch below *kl* and *lj* and parallel thereto. The vertical web under the pad is $\frac{1}{2}$ inch thick; so vertical lines are drawn through *q* and *r*, $\frac{1}{4}$ inch on each side of the middle point *s* of the edge *kl*. Similarly, the line *t* is drawn vertical, $\frac{1}{4}$ inch from the line *hf*. The holes in the pad are represented by ellipses whose long diameters incline to the right.

107. Oblique Drawing of Circles.—A circular outline on a vertical front face of a piece appears in its true circular form in an oblique sketch, as has been shown in Fig. 76. If the circle is on a horizontal face or a vertical side face, it will appear as an ellipse in the oblique sketch. The drawing of an oblique view of a horizontal circle is shown in Fig. 77 (*a*). The axes *oa*, *ob*, and *oc* are drawn and the center of the circle is assumed to be at *o*. On *ob* and *oc* prolonged, half the diameter of the circle is laid off from *o* to *d*, *e*, *f*, and *g*, and through these points the diamond-shaped figure *hijk* is drawn by lines parallel to *ob* and *oc*. The arc *de* is drawn freehand, so as to be tangent to *hi* at *d* and to *ij* at *e*; the arc *fg* is drawn tangent to *jk* and *kh* at *f* and *g*, respectively; then the arcs *ef* and *gd* are drawn to complete the outline, these also being tangent at the middle points of the sides of the diamond. The oblique view of a circle on a vertical side face is drawn as in (*b*), the method being practically the same as that just described.

PICTORIAL SKETCHES OF PIPING

108. Advantages.—In pipe installations, where various lengths of pipes and kinds of fittings are connected, the direction and level of the piping often change from point to point,

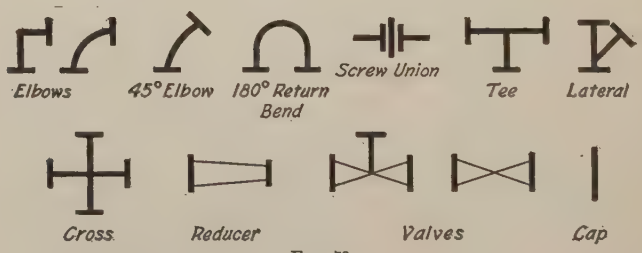


FIG. 78

at times making it difficult to understand the relative positions of the parts, if the sketch consists of only a top view. This difficulty is overcome to some extent by the addition of a side view and an end view. But, even so, the attempt to combine the several views into one while seeking to obtain a clear understanding of the whole is effected with difficulty and has to be repeated in examining each separate branch. It is in cases of

this kind that a pictorial sketch of a piping installation is of particular advantage.

109. **Conventional Symbols.**—To simplify sketches of piping, certain symbols are used to represent the various fittings. The more important of these are shown in Fig. 78, when applied

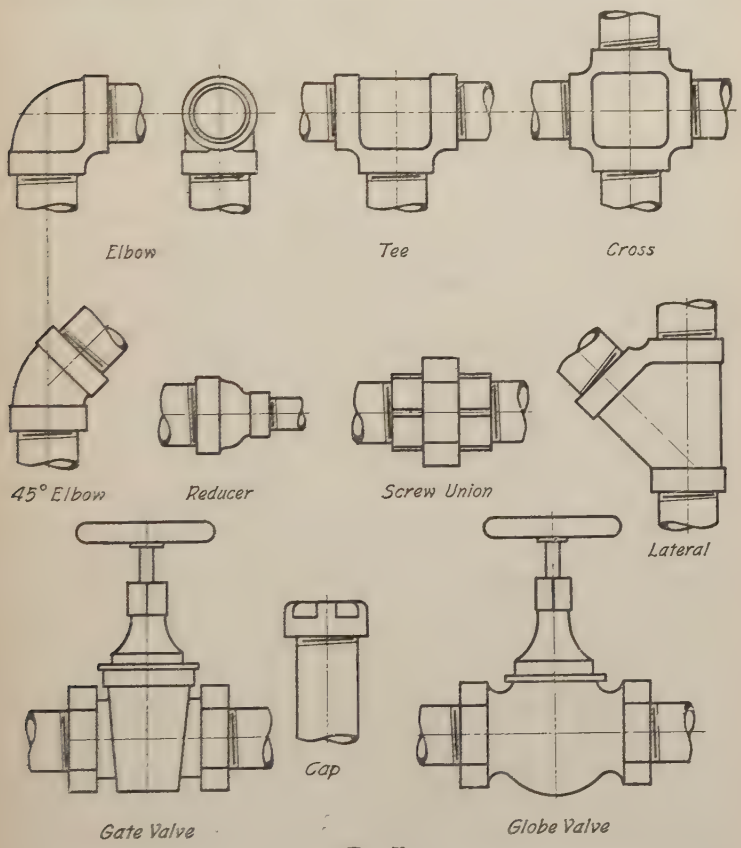


FIG. 79

to sketches in which the pipes are represented by one line only. If the pipes are indicated by two parallel lines, the outlines of fittings shown in Fig. 79 are used.

110. **Piping Diagrams.**—A diagram representing an ordinary plan, or top view, of a piping layout is shown in Fig. 80,

which also illustrates the application of some of the symbols shown in Fig. 78. The same installation is shown in an oblique single-line sketch in Fig. 81, which at first glance shows its advantage over Fig. 80, as to clearness and readability. In Fig. 81 three axes are used, a vertical, a horizontal, and one inclined at 30° to the horizontal.

As the piping installation, Fig. 81, is supposed to be supplied with water from a pump located on a lower floor, it will simplify the description if the passage of the water from point to point

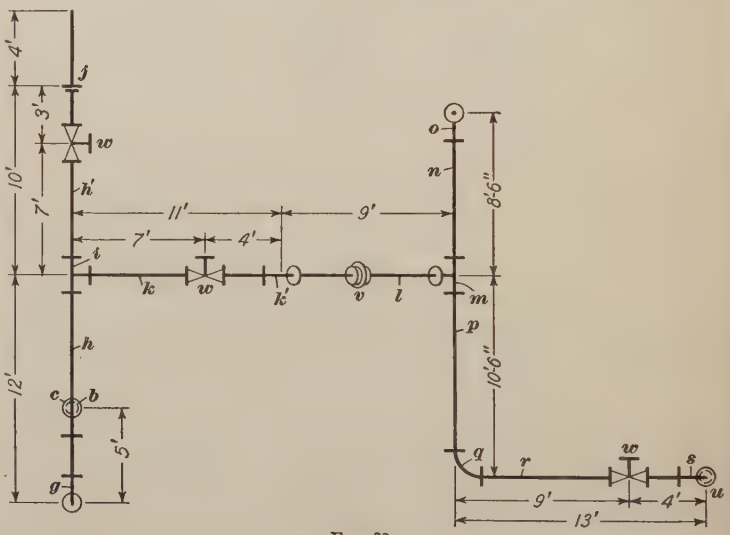


Fig. 80

is considered. The water enters the vertical pipe *a*, known as a *riser*, which passes through the floor flange *b*. It then passes through the elbow *c*, the pipe *d*, the elbow *e*, the riser *f*, and the elbow *g* into the horizontal pipe *h*, which connects with the tee *i*. At this point the water current divides into two branches, one flowing through the pipe *h'*, which leads through a wall, as indicated by the wall plate *j*. The branch *k* conveys water to the 45-degree elbow *k'* to the pipe *l*, inclined at an angle of 45° to the horizontal. At *m* the current again divides into two branches, one passing through the pipe *n*, the elbow *o*, and the riser *o'* to the floor above, the other passing through the pipe *p*,

the elbow q, the pipe r, and the elbow s down through the pipe t, which leads through the floor flange u to the floor below.

111. The advantage of the oblique sketch, Fig. 81, over the plan, Fig. 80, is easily seen by comparing corresponding portions, similar parts in every case being indicated by similar reference letters. Beginning, as before, with the riser a, it is seen that Fig. 80 shows only the floor flange b and the horizontal

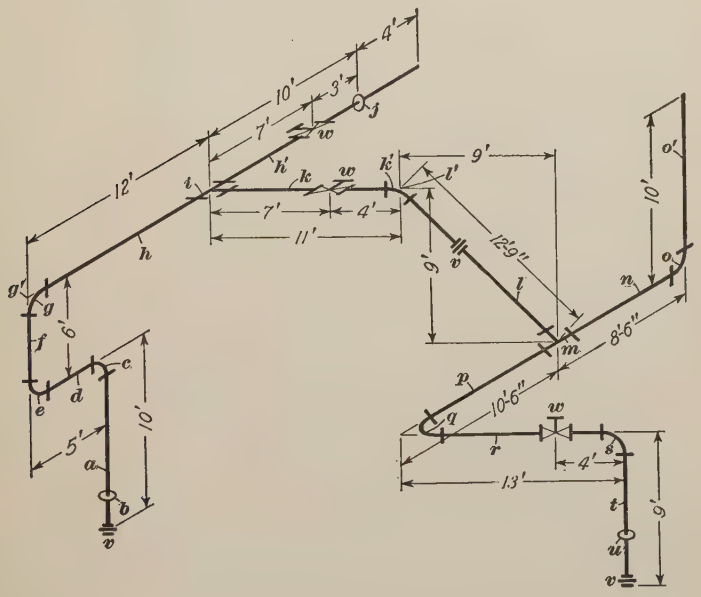


FIG. 81

flange of the elbow c; the pipe d and the adjoining portions of the elbows c and e are hidden by the pipe h situated directly above them. The inclined position of the pipe l and the adjoining portions of the elbow k' and the tee m is not indicated, except by the slanting flanges of these parts, represented as ellipses. Neither are the combinations of the elbow o with the riser o' nor the elbow s with the pipe t clearly shown. It is evident that the piping plan must be supplemented with a side view and an end view of the installation to illustrate the various inclinations and curvatures.

112. For sketching purposes, where the principal aim is to show the relative positions and lengths of the parts composing a piping installation, a single-line sketch, as Fig. 81, will serve most purposes, as the added dimensions give the required lengths and positions.

Where the pipes are represented by two parallel lines and the main features of the fittings are to be shown, a diagram similar to Fig. 82 may be made in which the fittings, as shown in Fig. 79, are incorporated. In Fig. 82, a tee is shown at *a*, 90-degree elbows at *b*, a screw union at *c*, and a valve at *d*.

113. **Developed Piping Diagram.**—Sometimes it is desirable to convert a piping diagram, such as Fig. 81, into a

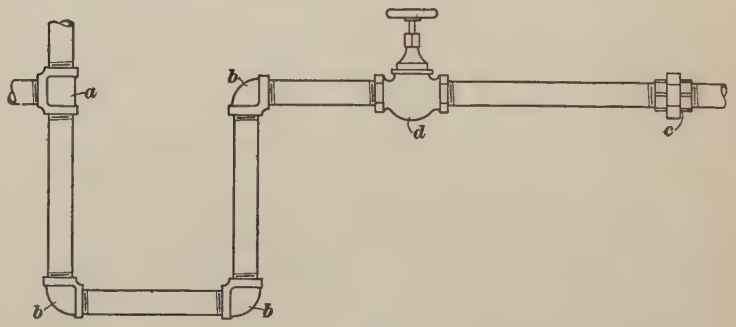


FIG. 82

developed piping diagram. The diagram, Fig. 83, represents the development of Fig. 81 and may be supposed to represent the piping laid out flat on a floor with the elbows, tees, and pipes turned so as to lie in the same plane. Evidently, the diagram shows the true shape and length of each part, as well as the correct distance between centers. The diagram may be said to represent the assembling of the parts before their final installation.

As in Fig. 81, the length of each branch or bend is measured from center line to center line of the pipes between which the bend is located. Thus, the length of the bend *f* in Figs. 81 and 83 is measured from the center line of the pipe *d* to that of the pipe *h*. The length of the branch pipe *k* is taken from the center

line of the pipe h, or h', to the point l', where the center lines of the pipes k and l intersect. Similarly, the space occupied by an elbow, such as g, is ascertained by measuring the distance between the point g' to the face of each flange.

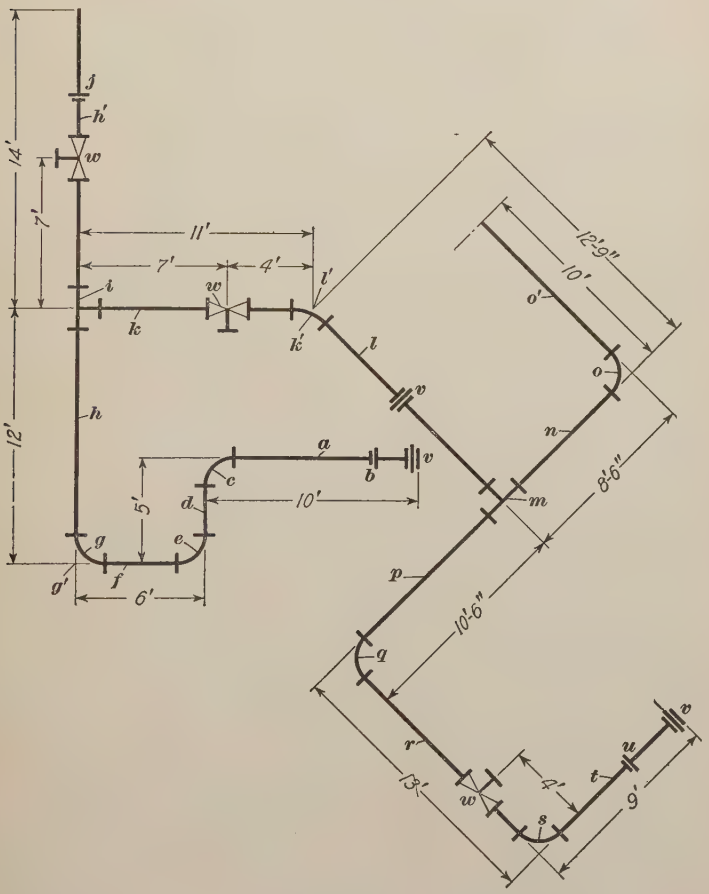


Fig. 83

For the purpose of erection, screw unions must be inserted at convenient points. In Figs. 81 and 83 such unions are shown at three places, indicated by v. Also, to enable either one of the branches to be closed, valves are located at w.